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Division of Energy
Wind Energy Program

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Division de l'énergie
Programme d'énergie éolienne

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Technical Memorandum

Proceedings of the Fifth International Meeting of Test Stations for Small Wind Energy Conversion Systems (IMTSS)

Atlantic Wind Test Site

August 1985

Canada

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PROCEEDINGS OF THE FIFTH INTERNATIONAL MEETING OF TEST STATIONS FOR SMALL WIND ENERGY CONVERSION SYSTEMS (IMTSS)

Atlantic Wind Test Site
North Cape, Prince Edward Island
CANADA

August 21, 22, 23, 1985

Prepared under SSC Contract No. OsR84-00233
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for National Research Council Canada

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SUMMARY

The fifth International Meeting of Test Stations for Small Wind Energy Conversion Systems (IMTSS) was held in Prince Edward Island, Canada from August 21 to August 23, 1985. The meeting was hosted by Canada's National Test Station, the Atlantic Wind Test Site, with financial assistance provided by the Wind Energy Research Program of the National Research Council of Canada's Energy Division.

The IMTSS is an informal international association of test stations and research centers that was created to provide a forum for the sharing of information and experience related to the testing, evaluation, certification, and standards for wind energy equipment and design.

The Canadian meeting was held at the Mill River Resort and at the Atlantic Wind Test Site at North Cape, Prince Edward Island. It was attended by 28 delegates representing 12 test stations and wind energy research programs in Europe and North America.

The meeting was highlighted by the following:

(1) Presentation of current status reports on each of the test stations.
(2) Presentation of technical reports.
(3) A meeting of the European members who are undertaking joint projects under the Council of European Communities.
(4) Informal arrangements for cooperation between individual test stations.
(5) The informal contacts between individuals.

The 1986 meeting will be held at Schnittlingen in the Federal Republic of Germany. It will be organized by DFVLR, possibly to coincide for travel purposes with the International Wind Energy Symposium to be held in Rome in October 1986.

RÉSUMÉ

La Cinquième Réunion internationale des stations d'essais des petits systèmes de conversion d'énergie éolienne (IMTSS) a eu lieu à l'Île du Prince Édouard, au Canada, du 21 au 23 août 1985. L'hôte de la réunion était la station d'essais nationale du Canada, le Site d'essais éoliens de l'Atlantique, qui à ce titre avait reçu l'aide financière du Programme de recherche sur l'énergie éolienne de la Division de l'énergie du Conseil national de recherches du Canada.

L'IMTSS est une association internationale officieuse de stations d'essais et de centres de recherches mise sur pied pour promouvoir le partage de l'information et de l'expérience relatives à l'essai, à l'évaluation, à l'homologation et aux normes des matériels et des conceptions du domaine de l'énergie éolienne.

La réunion canadienne s'est tenue au Mill River Resort et au Site d'essais éoliens de l'Atlantique, à North Cape (Île du Prince-Édouard). Y ont assisté 28 délégués représentant douze stations d'essais et programmes de recherche sur l'énergie éolienne d'Europe et d'Amérique du Nord.

Voici les points saillants de la rencontre :

(1) Présentation de rapports faisant le point sur chacune des stations d'essais;
(2) Présentation de rapports techniques;
(3) Réunion des membres européens pilotant des projets communs sous l'égide du Conseil des communautés européennes;
(4) Établissement d'ententes officieuses de coopération entre des stations d'essias;
(5) Établissement de liens officieux entre des personnes.

La réunion de 1986 aura lieu à Schnittlingen, en République fédérale d'Allemagne. Elle sera organisée par le DFVLR et coïncidera probablement, pour simplifier les déplacements des délégués, avec le Colloque international de l'énergie éolienne qui sera tenu à Rome en octobre 1986.

MINUTES

Wednesday, August 21, 1985

08:30 Call to Order-Malcolm A. Lodge

-Welcomed delegates and made some general announcements regarding assembly and travel.
-Reviewed Agenda.

09:10 CEC Project Review Meeting

-Opening remarks by H. Nacfaire representing the Council of European Communities.
-Discussion on follow-up of previous meetings in Lannion, France in 1984.
-Twelve joint activities were discussed as described in Lannion meeting minutes.
-Proposal 1 (Benchmark Test Power Curves) and Proposal 4 have been combined as one project; Helge Petersen and Jan Dragt are project leaders.
-Proposal 5 (Accident Statistics), Proposal 7 (Safety Philosophy), and Proposal 8 (Safety and Function Test) have also been combined as one project with Jan Dragt and Jens Peter Molly as project leaders.
-Proposal 2 (Round Robin Tour of Wind Turbines) has been postponed.
-Proposal 6 (Wind Gust Statistics); Jens Peter Molly has submitted a project proposal to CEC.
-Proposal 11 (Noise Measurements); George Elliot mentioned that there has been no response from other test stations to his questionnaire on this subject. He will send a proposal to CEC.
-Proposals 3, 10, and 12 had no progress to report.

11:30 - 16:00 General presentations commenced in which each test station gave a summary of their status, developments and future plans.

Presentations given were:
1. Atlantic Wind Test Site - Carl Brothers
2. Risø - Helge Petersen
3. U.K. National Energy Laboratory - George Elliot
4. Alternative Energy Institute - Vaughn Nelson
5. Lethbridge Test Station - Brent Paterson
6. Schnittlingen - Jens Peter Molly
7. CWD - Niko Pieterse

18:00 Banquet

-Seafood Delight generously hosted by the Prince Edward Island Department of Energy and Forestry. Speaker was Leo Walsh, Deputy Minister of the Department.

Thursday, August 22, 1985

09:00 - 10:30 Meeting called to order. Continued general presentations from the previous day.

Presentations given were:

8. Rutherford Appleton Laboratory - Ervin Bossanyi
9. ENEA (Italy) - Gaetano Gaudiosi
10. ECN (Petten, Germany) - Wim Stam
11. Fiskebark/Chalmers University of Technology - Ola Carlson
12. Project EOLE Cap Chat - Bernard Saulnier, Jacques Plante

10:40 - 15:00 Technical Presentations Commenced.

Presentations given were:

1. A Discussion of the Canadian Standards Association Proposed Performance Standard - Ray Richards
2. Activities and Data Acquisition at the Lethbridge Test Station - Dave Baker
3. Wind Power Activities in the Bahamas - Eric Jensen
4. Short Term Measurements to Investigate Starting Behavior of Wind Pumps - Niko Pieterse
5. Effect of Overestimating Cp Because of "Energy Pattern Factor" of 10-Minute Averaging - Heinz-Theo Mengelkamp
6. Project EOLE - Bernard Saulnier
7. Technical Activities at ECN Petten - Wim Stam
8. Wind Diesel Work at Risø - Helge Madsen
9. Eigenfrequencies - Per Lading
10. Licensing Windmills in Denmark - Peter Hjuler Jensen
11. Schnittlingen Technical Activities - Jens Peter Molly

15:00 Closing discussions indicated a fruitful meeting. Malcolm Lodge thanked participants for their participation and presentations. Preceedings will be sent to participants.

The next meeting of IMTSS will be held in Schnittlingen in the fall of 1986, organized by DFVLR, possibly to coincide for travel purposes with the International Wind Energy Symposium to be held in Rome in October 1986.

LIST OF DELEGATES*

The meeting was attended by the following persons:

BELGIUM	Brussel	Hubert Nacfaire
CANADA	Alberta:	David Baker
		Brent Paterson
		Eric Jensen
	Ontario:	Jim Keller
		Ray Richards
	Prince Edward Island:	Malcolm Lodge
		Hal Arthurs
		Carl Brothers
		Rick Smith
		Gary Wedge
	Quebec:	Jacques Plante
		Bernard Saulnier
DENMARK	Risø	Peter Jensen
		Jorgen Krosgsgaard
		Per Lading
		Helge Madsen
		Helge Petersen
GERMANY	Geesthacht	Heinz-Theo Mengelkamp
	Stuttgart:	Jens Peter Molly
ITALY	Rome:	Gaetand Gaudiosi
NETHERLANDS	Amersfoort	Niko Pieterse
	Petten	Wim Stam
SWEDEN	Goteborg	Ola Carlson
UNITED KINGDOM	England	Ervin Bossanyi
	Scotland:	George Elliot
		Allan Johnston
UNITED STATES	New Mexico	Walter Jackson
	Texas	Vaughn Nelson

*See Appendix A for addresses.

International meeting of test stations for SWECS
Atlantic Wind Test Site (Canada)

21 - 23 August 1985

COMMUNITY ACTIVITIES IN WIND ENERGY

H. NACFAIRE

Commission of the European Communities
Directorate-General for Energy

It is a great pleasure for me to visit this large country engaged as early as 1973 in wind energy and I am pleased that the European Commission is able to participate in this 1985 International Meeting of test stations for SWECS.

But before developing the subject of wind energy and the Community's activities in this field, I should like to describe briefly the demonstration programme, of which wind energy is a small, but important part.

1. DEMONSTRATION PROGRAMME

This is a programme whereby the Community grants financial support to innovative projects in the field of energy; the areas covered are :

- energy saving,
- liquefaction and gasification of solid fuels,
- solid fuels for hydrocarbon substitution,
- new uses of electricity and heat and
- alternative energy sources.

Alternative energy sources cover solar energy, biomass and energy from waste, geothermal, wind energy and hydro-electric power.

The aim of the programme is to demonstrate for the first time that a new technology can be commercially viable; it follows therefore that demonstration projects are beyond research and development and on the threshold of commercialisation. In bridging the gap between R+D and full commercialisation inevitably some risk, both technical and economic, is incurred. Many successful researches fail to get exploited because enterprises are reluctant to bear the entire risk entailed in a full-sized implementation.

The technical risk arises because either the components of the system have never been tested on a commercial scale application or the separate parts of the system have never been put into operation together. One of the results of demonstration is thus to confirm the system parameters or suggest an optimum configuration.

The economic risk comes from two sources : firstly the investment, installation and operating costs of the system may be higher than expected; secondly economic parameters may change unfavourably: these are the cost of conventional fuel sources, interest rates, exchange rates or inflation.

It is clearly consistent with Community energy strategy to bring forward good projects quickly; therefore the Community is prepared to share the risk contractually to the extent of granting up to 49% of the eligible cost of the project.

It is also crucial that projects selected for support have a potential for replication not only in the Member State where the demonstration is carried out, but also in other Member States.

Since 1978 a total of 804 projects supported by the Community were selected from over 3000 proposals forwarded to the Commission. The total support allocated to these projects is over 400 million Ecus bringing the total investment associated with Community energy projects so far to over 2000 million Ecus.

To provide continuity to the demonstration programme and further support to an ever-growing industry, the Commission has presented to the Council of Ministers proposals for a new programme. This programme has now been accepted and will run from 1986 for four years.

I would like to mention in passing that in parallel with the demonstration programme developed by my Directorate-General, a new programme of R & D for the renewable energies has just been launched by the Directorate-

General for Science, Research and Development. In this four year programme 18 million Ecus have been allocated for the wind energy sector and concern the development of Technologies and Prototypes.

2. WIND ENERGY SECTOR

Realistic estimates for the potential of wind energy have indicated that this energy source could provide 2% of the Community's electricity by the year 2000. To enhance this possibility, the Commission of the European Communities published the third call for tender in wind energy last December. In the 1983 and 1984 call for tender 56 projects were selected. They receive a Community financial support of 14.7 million Ecus representing a total project investment of more than 45 million Ecus.

The financial aid granted by the European Commission applies to the stages of :

- design,
- construction,
- demonstration phase.

This latter phase comprises a measuring programme which makes it possible to establish the essential characteristics of the installation and to compare them with the initial expectations concerning

- energy production,
- economic viability,
- maintenance costs,
- technical problems.

The projects relate to various fields of application and size, grouped as shown in table I.

The distribution of projects indicates that the production of electricity is the most significant application. The projects involving connection to the national electricity grids in general incorporate large or, medium sized wind turbines.

The largest part of the projects aim at the production of electricity for island grids by medium sized wind turbines. These projects are already considered to be economically sound, because of the high costs of fuel for electricity production at those sites and of the high wind velocities which generally occur there.

The autonomous electricity production systems are mostly small wind turbines combined with diesel engines of approximately the same power output as the wind turbines. In these situations the diesel engine provides the certainty of the power supply, whilst the wind turbine serves to reduce the overall fuel consumption.

Mention should also be made of other applications for heating, water pumping, desalination etc. .

As can be seen on the map of Europe, nearly all the projects are located near the coasts and on islands where the highest wind speeds are found (Figure II).

3. OTHER ACTIVITIES

To stimulate the development of wind energy in the Community, the Directorate-General for Energy has initiated three operations which are being run in parallel with the demonstration programme.

The first involves a critical and comparative study of the legislation which may affect the development of wind energy in the Member States of the Community. A preliminary report has been drawn up and has been discussed in November 1984 by the national experts. This report deals with the following points :

- construction and operating permits for wind energy installations;
- construction and safety rules;
- insurance of the plant;
- the generation of electric current and the method of connection to the electric grid;
- official aid.

The report will soon be updated. In addition, the regulatory measures will be incorporated into a data-base accessible through public information networks to all users.

The second operation concerns a market study of small and medium sized wind turbines. The report of this study will be discussed by national experts in Brussels at the beginning of 1986.

The third operation and the most important concerns increasing collaboration between the national test stations for windmills. From the beginning of 1983 the Commission offered to support the initiative taken by Petten and Risø to exchange information on an informal basis.

The objectives of the European Commission in supporting work executed in the existing national test centres must be to ensure coordination of their activities and to encourage through these centres, the evolution of common standards and certification procedures. This should favour the development of a competitive industry in a much larger and more open market.

A first report has been drawn up in conjunction with the three national test centres : Petten (Netherlands), Risø (Denmark) and Schnittlingen (Germany). This report covers the :

- recommended tests,
- development of measuring methods,
- safety systems and load cases.

The report also defines various areas of possible mutual cooperation. Three projects have been chosen and, are under way, carried out in close cooperation between more than ten test stations and subsidised by the CEC for the national stations of the Community.

These projects concern :

- administrative procedures for licensing of WEC's ,
- power curve computation and accuracy of power curve measurements,
- safety reliability philosophy,

for which the Petten, Risø and Schnittlingen centres are responsible.

In conclusion, the Commission is very pleased to see increasing cooperation between test centres and particularly the extension of cooperation with test centres outside the Community. We wish every success for this meeting and we hope that we will be able to define even more areas of cooperation, particularly in the areas which reflect the objectives of the Commission.

EVALUATION OF SMALL SCALE WIND TURBINES FOR PUMPING WATER IN ALBERTA

by

B. A. Paterson[1]; D. R. Baker[2] and N. E. Jensen[3]

ERRF #RP 89

FFF #81-0048

[1] Head, Drainage Branch, Alberta Agriculture, Lethbridge, Alberta

[2] President, DRB Engineering Consultants Ltd., Calgary, Alberta

[3] President, Jensen Engineering Ltd., Olds, Alberta

EXECUTIVE SUMMARY

In 1982 the Drainage Branch of Alberta Agriculture and Jensen Engineering Ltd. of Olds, Alberta, in conjunction with the Alberta Research Council, initiated a study to evaluate the use of wind turbines in Alberta to pump water and monitor, demonstrate and evaluate various types of wind turbines distributed in Canada. To meet these objectives a test site was established adjacent to a St. Mary River Irrigation District canal immediately east of Lethbridge, Alberta where a total of six different water pumping windmills were installed during the spring of 1983. Later, a solar pumping system and a small electrical generating wind turbine were also installed on the site.

All of the units were monitored on a continuous basis throughout the summer and fall seasons of 1983 and 1984, with the electrical generating unit monitored on a year-round basis. A number of parameters were monitored for each of the water pumping turbines with volume of water pumped relative to wind speed being considered the most important. For the solar unit, water pumped versus solar radiation was considered important while for the electrical unit, power output versus wind speed was measured.

The results of this study, particularly the demonstration aspects, have far exceeded expectations. Interest by farmers, industry and government has been high, with demonstration days held in 1983 and 1984 attracting crowds in excess of three hundred and two hundred respectively. Tours of the site have been arranged for interested groups from throughout North America and Europe, with numerous manufacturers expressing considerable interest in having their machines tested at this site.

The results of the testing program showed considerable differences among the various types of units on the site. More importantly, however, the program points out the necessity of relating the pumping performance of each machine (water pumped or power produced versus wind speed) to the wind regime data for a given region, in order to predict the true capability of a given wind turbine. The same concept holds true for the solar pumping system. The data also points out that wind turbine manufacturers should put greater emphasis on designing machines to capture the low end of the wind spectrum rather than attempting to maximize power at the higher wind speeds. For example, two of the wind turbines (Bowjon and Maverick) on the site have identical maximum pumping rates (12 gpm) but the Bowjon begins pumping water at a wind speed of 6 mph whereas the Maverick does not start pumping until the wind reaches 8 mph. This 2 mph starting difference results in the Bowjon pumping 40% more water annually than the Maverick at Lethbridge, where average wind speeds are quite high, and 83% more water annually at Edmonton where average wind speeds are relatively low.

The data monitored at the Lethbridge test site, because it is based on the International Energy Agency's (IEA) wind turbine performance testing standard, can be extrapolated and utilized throughout most of the world. This is valuable because manufacturers interested in exporting their turbines can now provide internationally accepted performance data to potential buyers. This export potential is expected to increase significantly as many developing countries attempt to find inexpensive yet effective means of pumping water to meet ever-increasing demands. The Lethbridge test program is the only one in

Canada and one of a very few in the world which can supply this kind of information, which gives Alberta and Canadian manufacturers a competitive edge in the world market.

WINDMILL TEST SITE

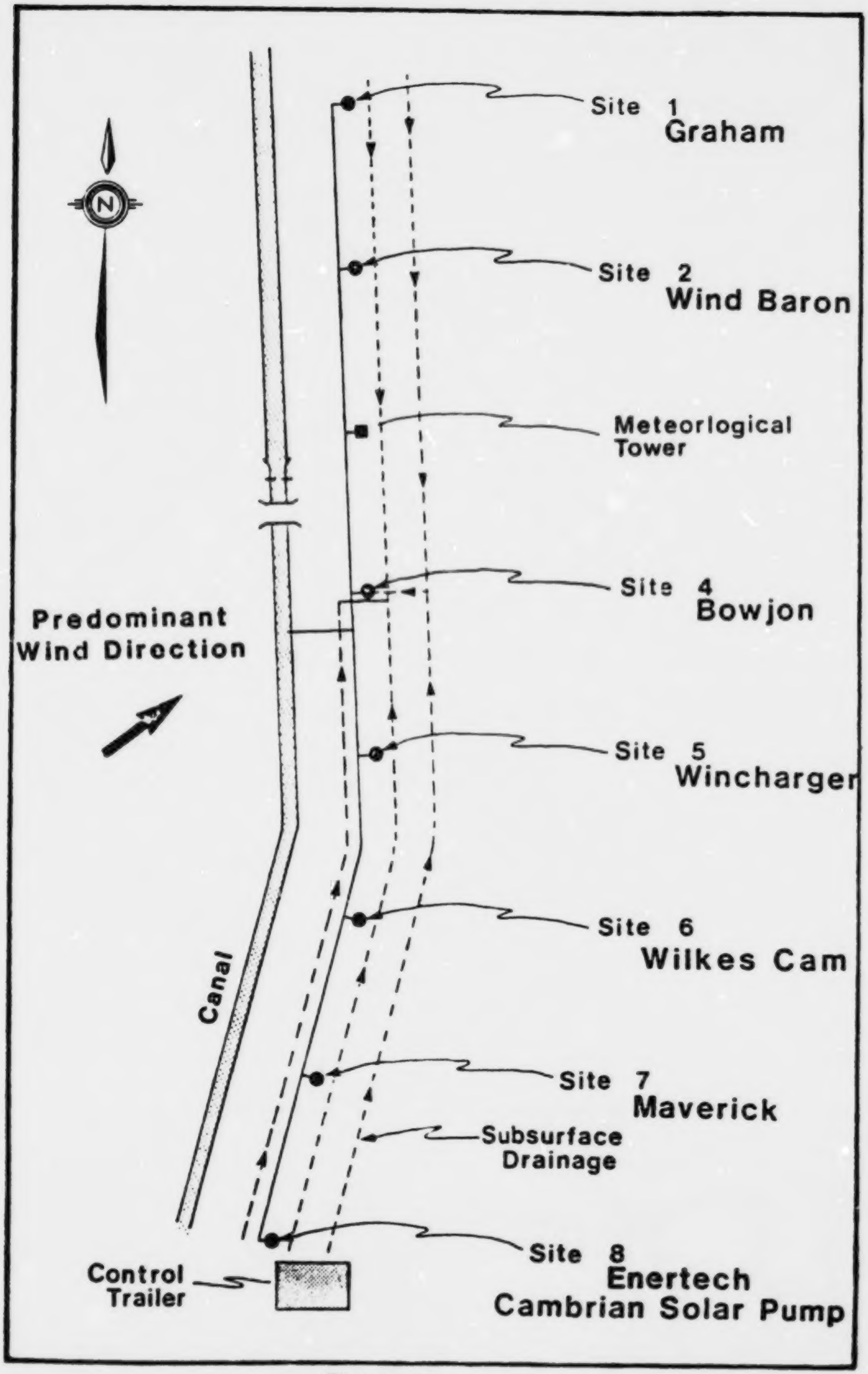

Site 1
Graham
Site 2
Wind Baron
Meteorlogical
Tower
Site 4
Bowjon
Predominant
Wind Direction
Site 5
Wincharger
Site 6
Wilkes Cam
Canal
Site 7
Maverick
Subsurface
Drainage
Site 8
Enertech
Cambrian Solar Pump
Control
Trailer
N

Figure 1

in this section would not raise the water level in the standpipe to a point where it would contribute to the pumping head of the wind turbine. The water exiting the metered pipe provided potential users with visual evidence of the wind turbine capabilities. The loop was completed when the pumped water returned to the first sump through a connecting pipe located near the base of the two sumps.

PUMPING CIRCUIT

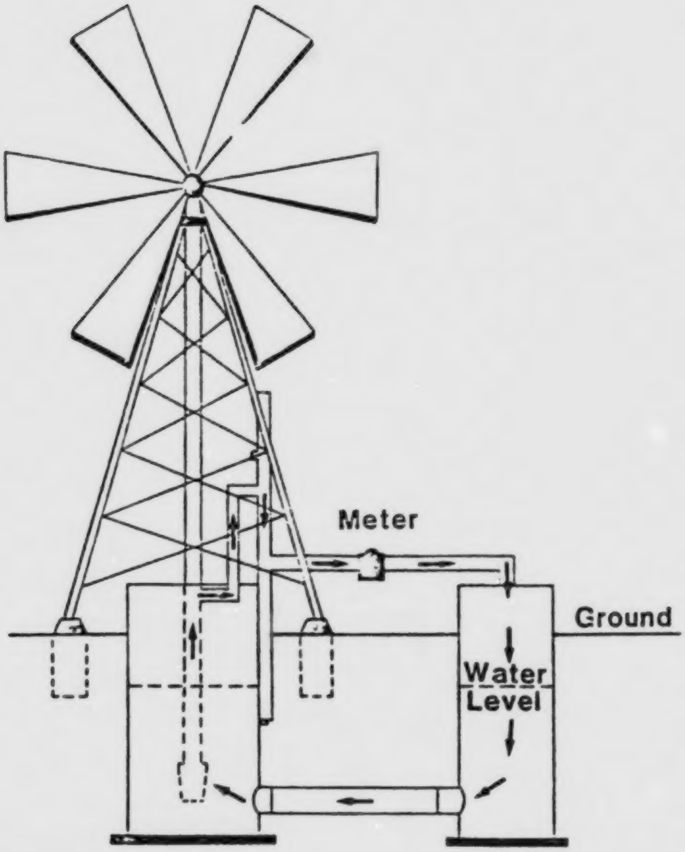


Figure 2

DESCRIPTION OF WIND TURBINES

The six water pumping wind turbines on the site represent a reasonable cross-section of units available on the market. The mechanical water pumpers include the Graham 12 at Site #1 (Figure 3), the Wind Baron at Site #2 (Figure 4) and the Wilkes Cam at Site #6 (Figure 5). The Wind Baron and Wilkes Cam units both have multibladed rotors ranging in size from 3.7 m diameter (Wilkes Cam), to the Wind Baron with a rotor diameter of 6.4 m. The Graham rotor measures 1.8 m high x 3.7 m across and is based on the Savonius principle. In addition, two airlift turbines are located at Site #4 (Bowjon - Figure 6) and Site #7 (Maverick - Figure 7). The subsurface drainage system discharges into

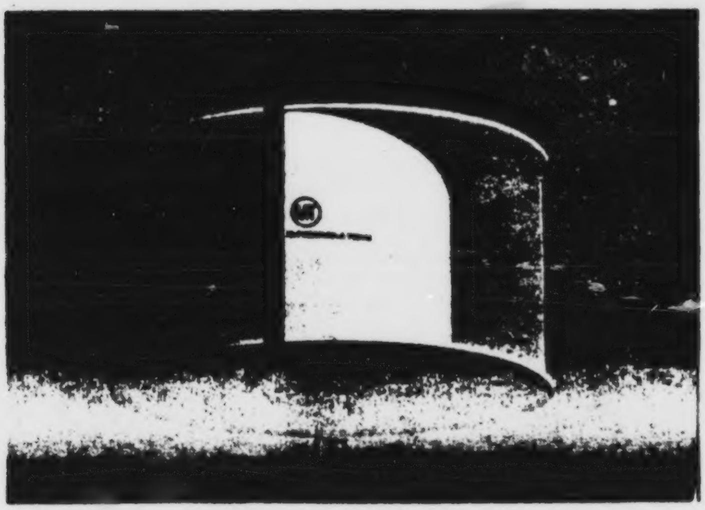


FIGURE 3 - GRAHAM 12

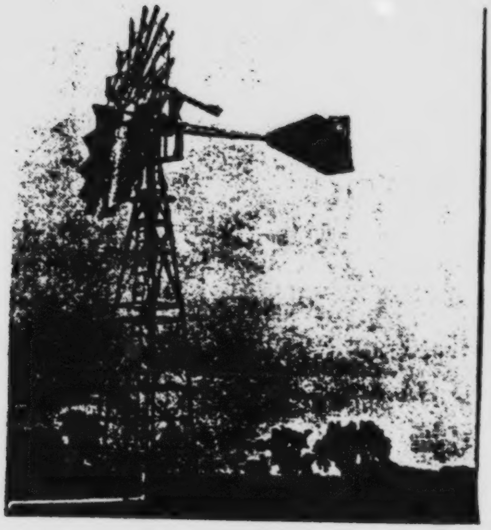


FIGURE 4 - WIND BARON

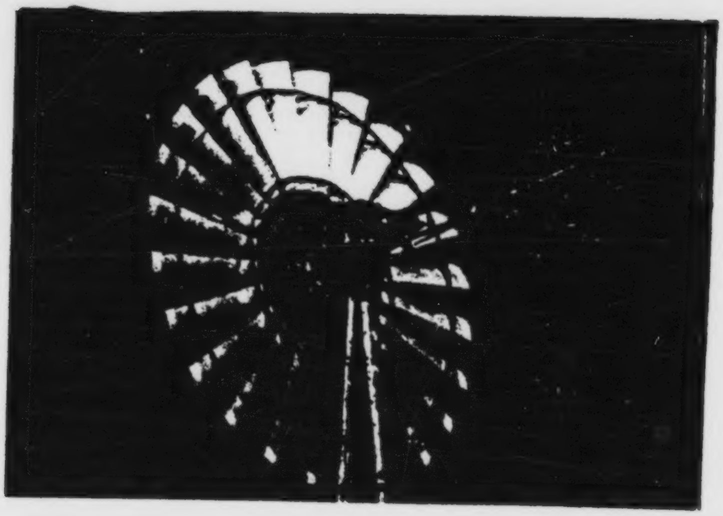


FIGURE 5 - WILKES CAM

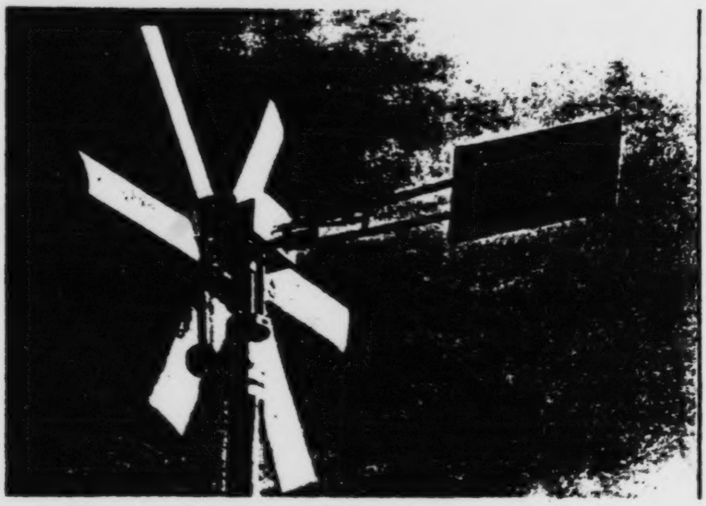


FIGURE 6 - BOWJON

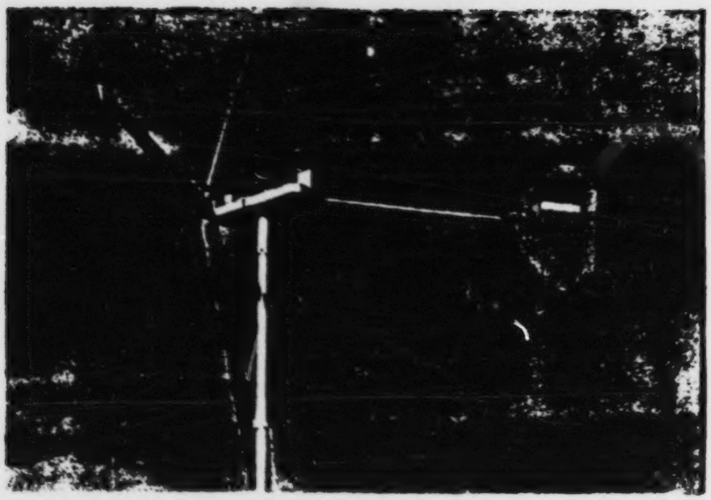


FIGURE 7 - MAVERICK

the Bowjon sump. These units use compressed air to lift water and are similar in design except that the Bowjon unit has a multibladed rotor while the Maverick has a three-bladed rotor. The last water pumping wind turbine on the site is the Wincharger electrical machine located at Site #5 (Figure 8). This unit uses a D.C. generator directly connected to the turbine rotor to produce power for a small centrifugal pump. One electrical generating wind turbine was also installed on the site in order to demonstrate its operational characteristics. This turbine is the three-bladed, horizontal axis Enertech 1800 which has a rated maximum output of 2100 W and is located adjacent to Site #8 (Figure 9). The unit is equipped with an induction generator, which produces sine-wave, 60 hz, 115 VAC within its range of operating speeds. This unit is designed to be interconnected to an electrical utility grid. The portable solar pumping unit which was installed at Site #8 (Figure 10) consists of

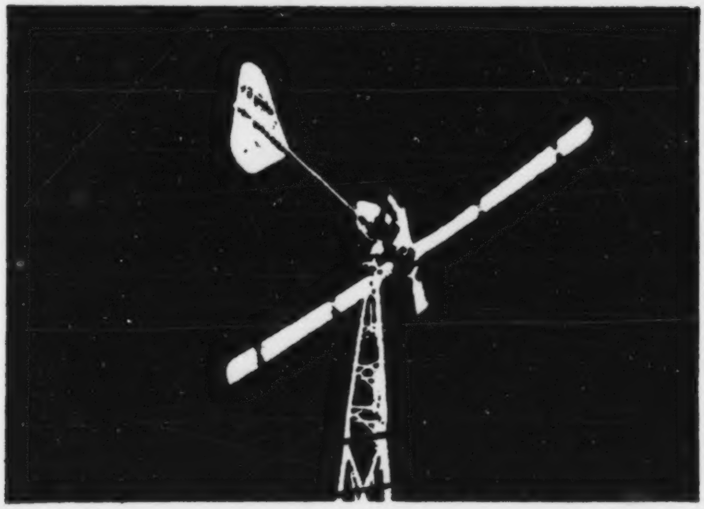


FIGURE 8 - WINCHARGER

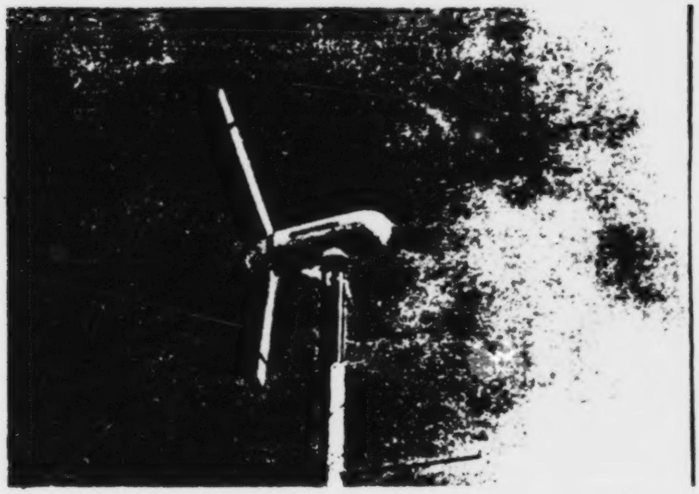


FIGURE 9 - ENERTECH

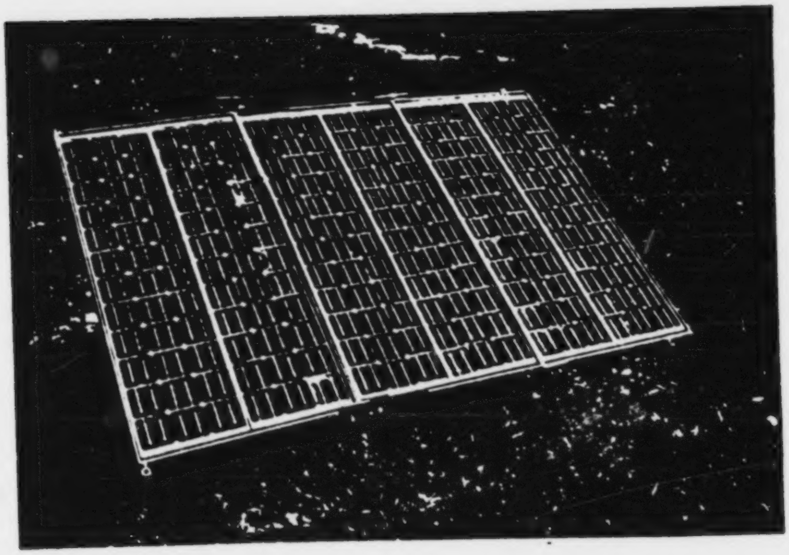


FIGURE 10 - CAMBRIAN SOLAR PUMP

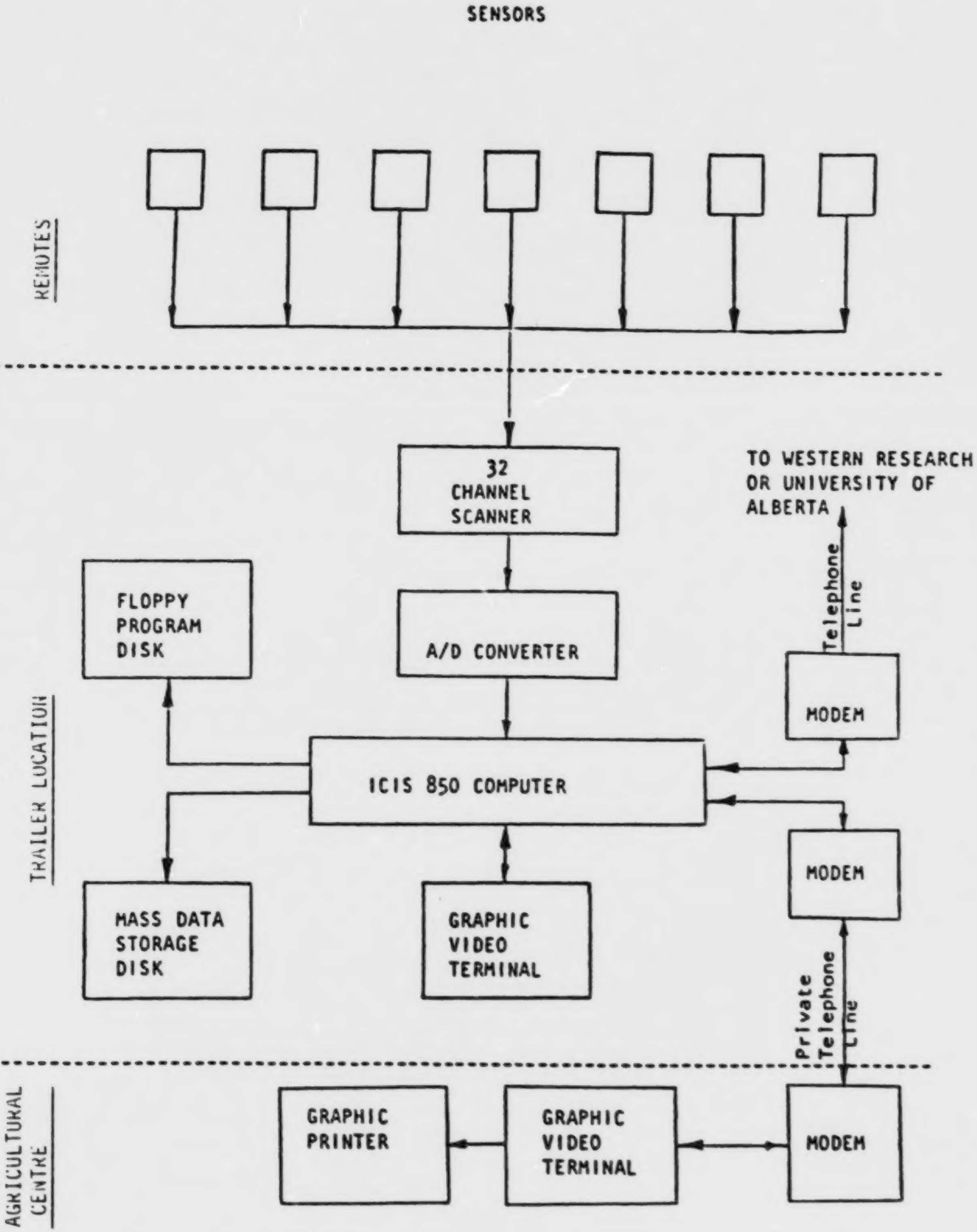
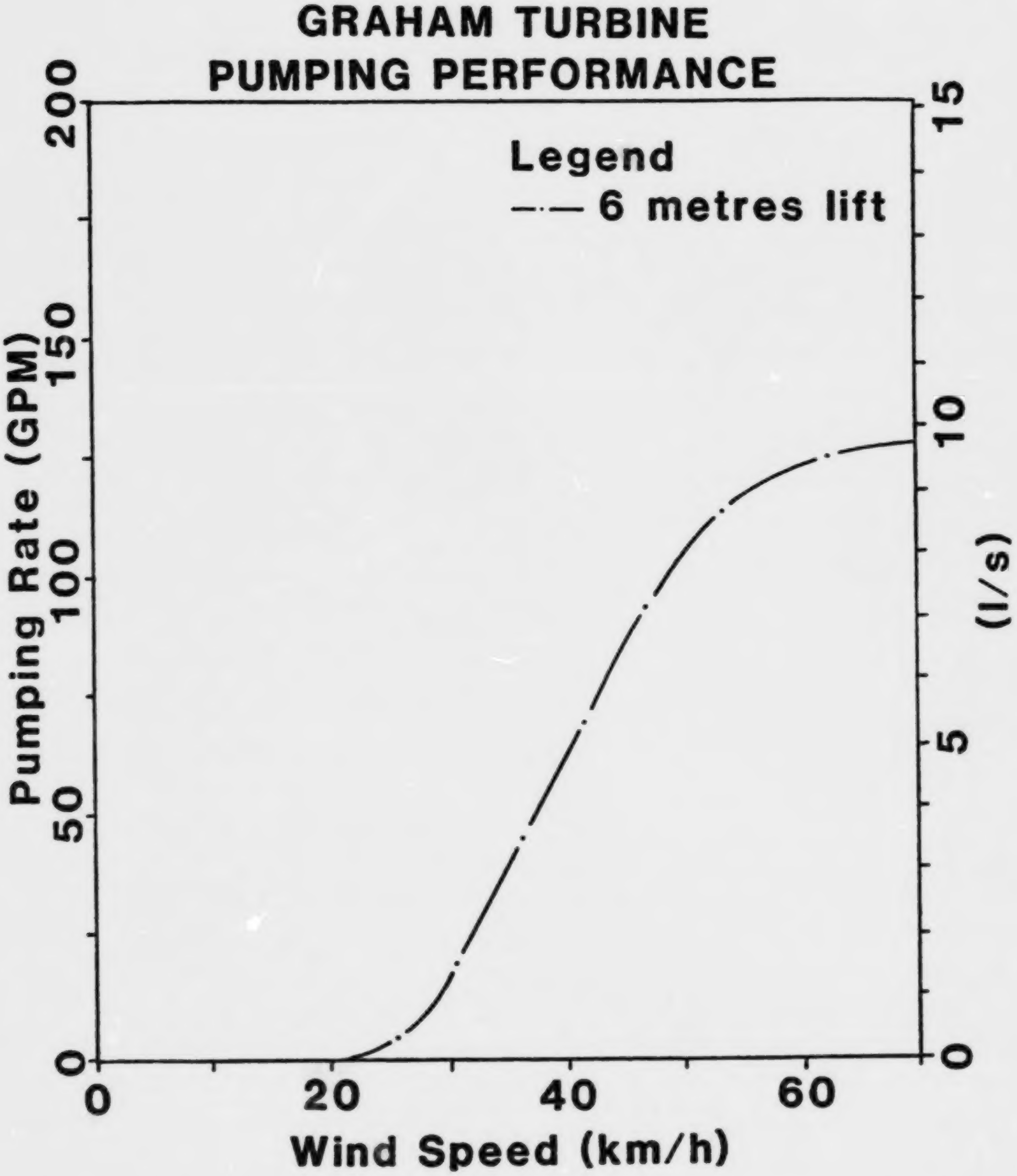
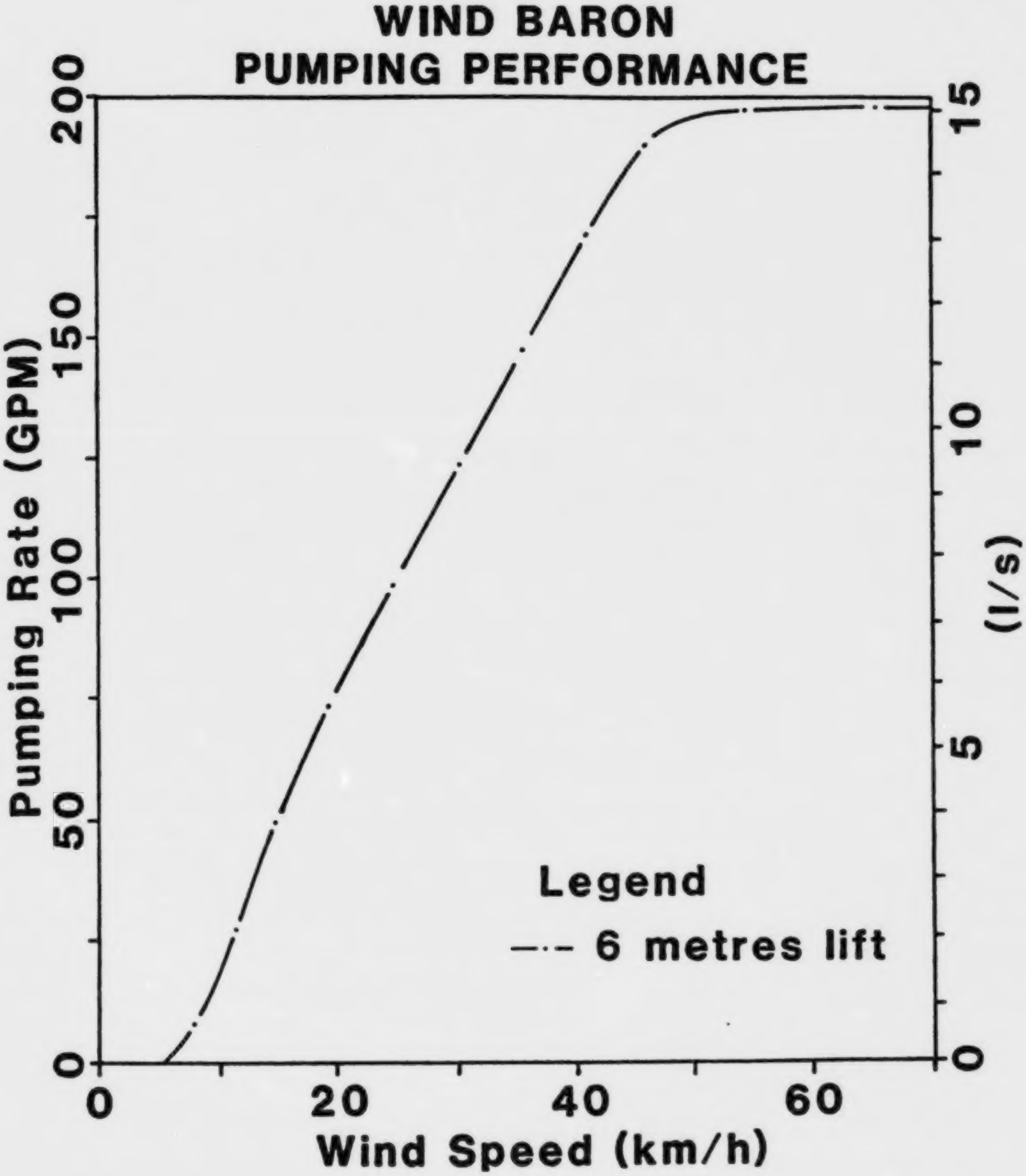

SENSORS
REMOTES
32 CHANNEL SCANNER
TO WESTERN RESEARCH OR UNIVERSITY OF ALBERTA
Telephone Line
FLOPPY PROGRAM DISK
A/D CONVERTER
MODEM
TRAILER LOCATION
ICIS 850 COMPUTER
MODEM
MASS DATA STORAGE DISK
GRAPHIC VIDEO TERMINAL
Private Telephone Line
AGRICULTURAL CENTRE
GRAPHIC PRINTER
GRAPHIC VIDEO TERMINAL
MODEM

Figure 11 Data Acquisition System



GRAHAM TURBINE PUMPING PERFORMANCE

Figure 13



WIND BARON
PUMPING PERFORMANCE

Figure 14

WILKES CAM PUMPING PERFORMANCE

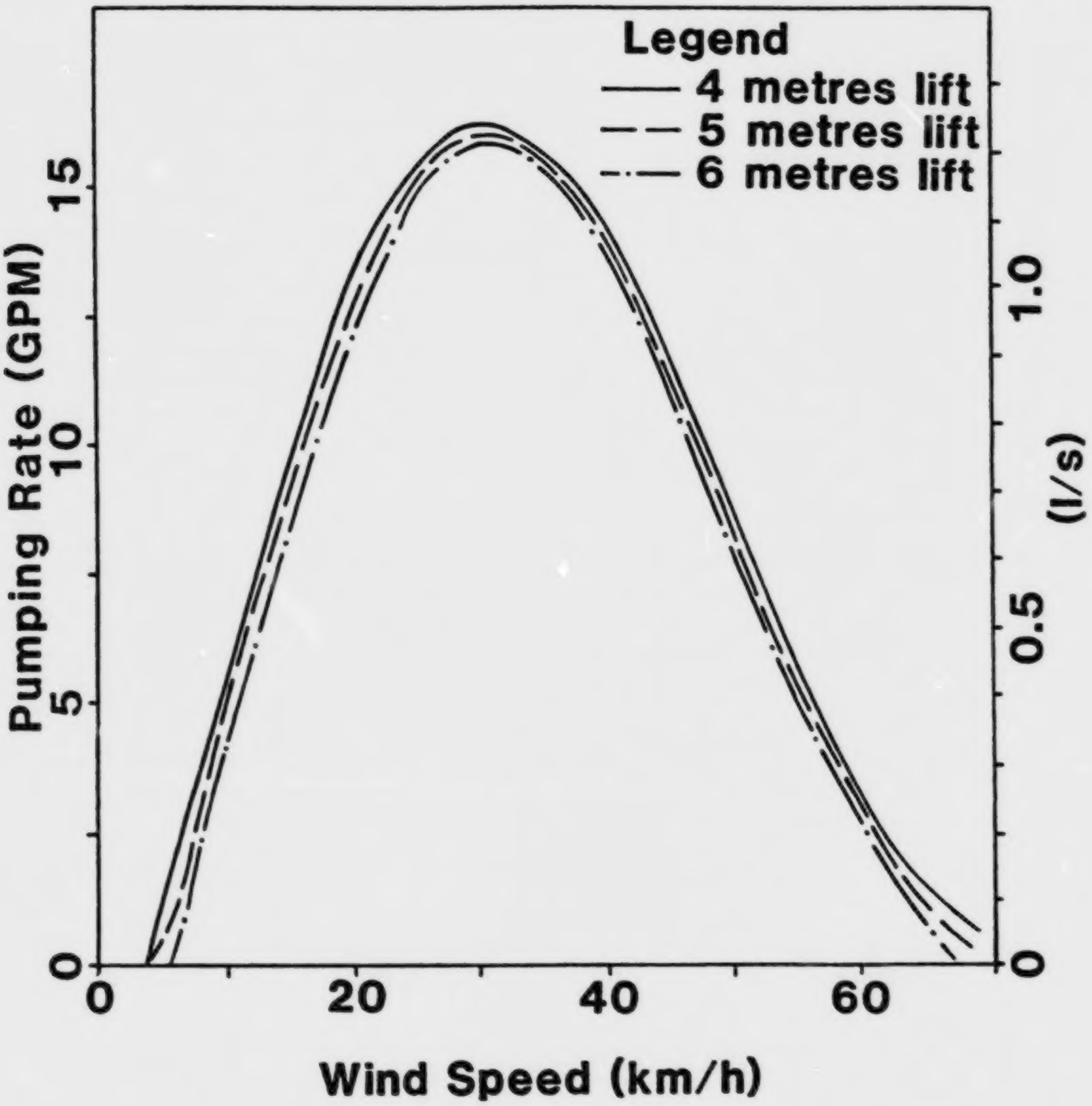
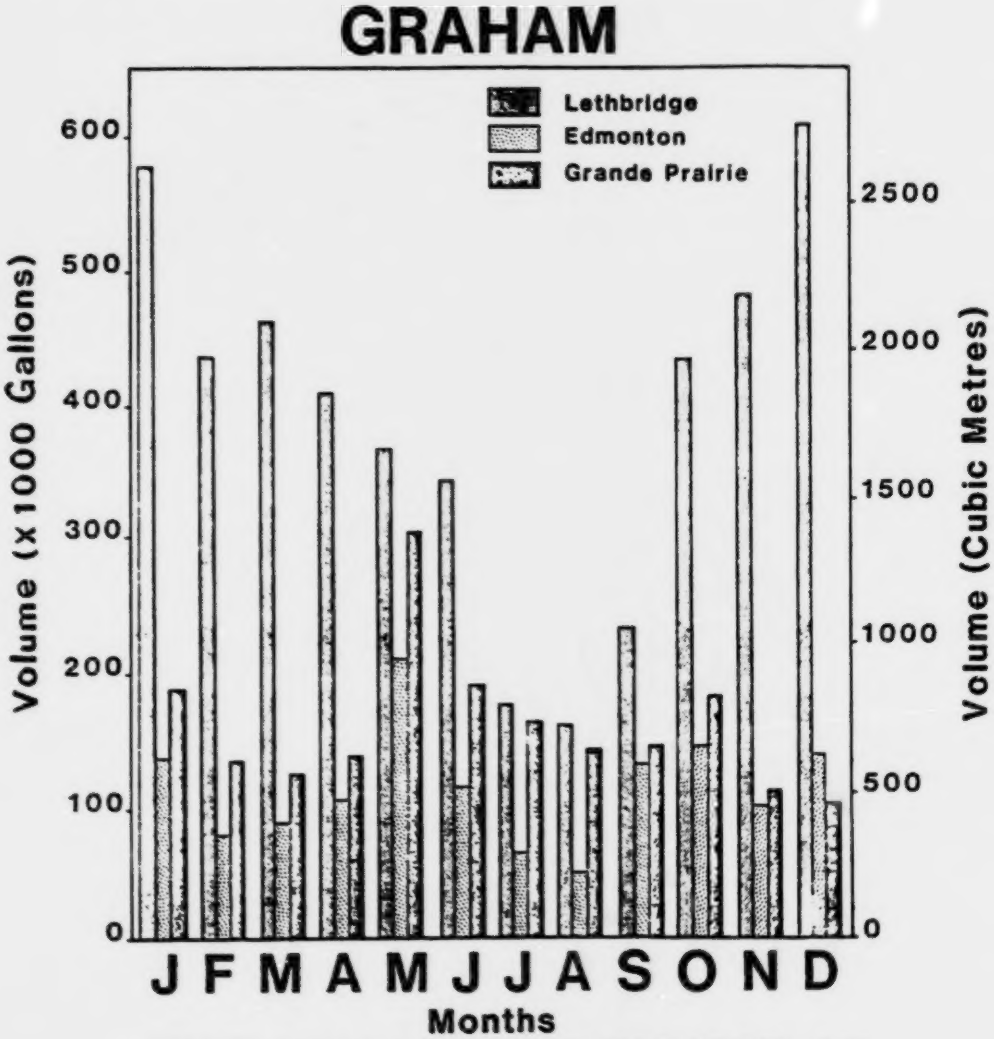


Figure 15

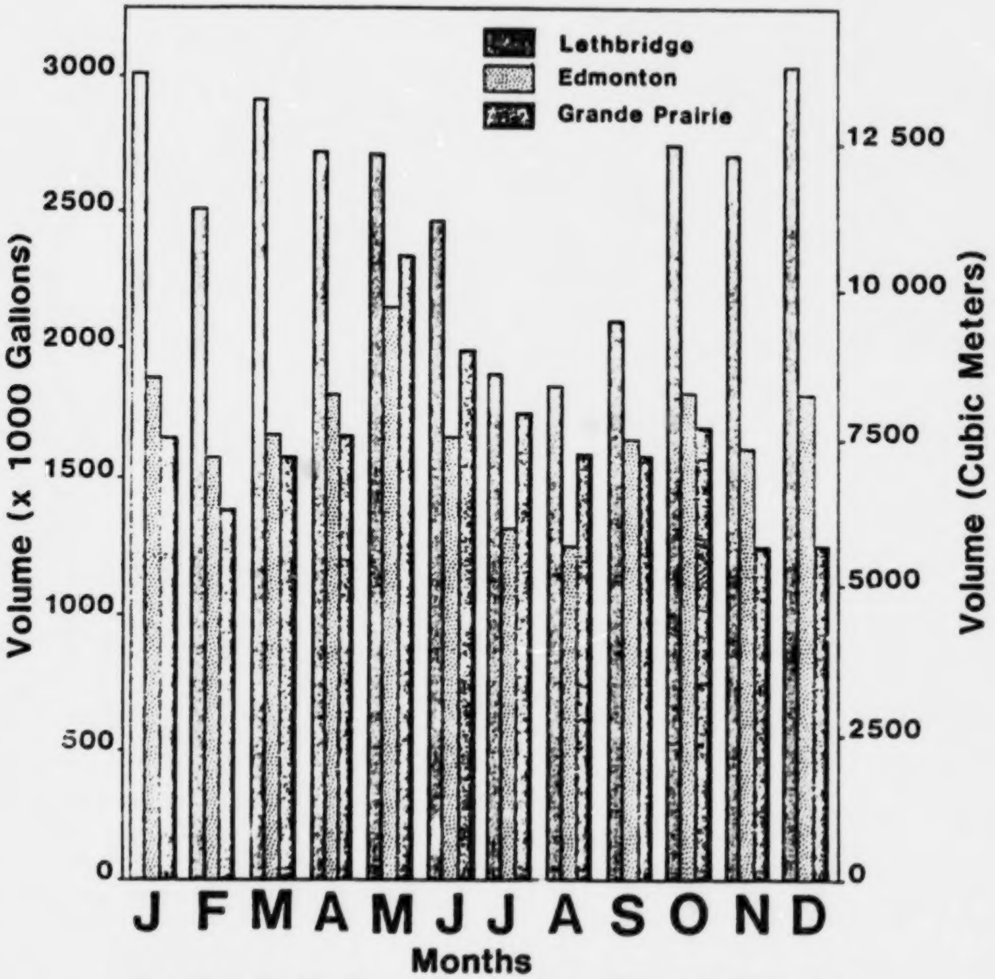


EXPECTED VOLUME PUMPED AT

6 m LIFT

Figure 16

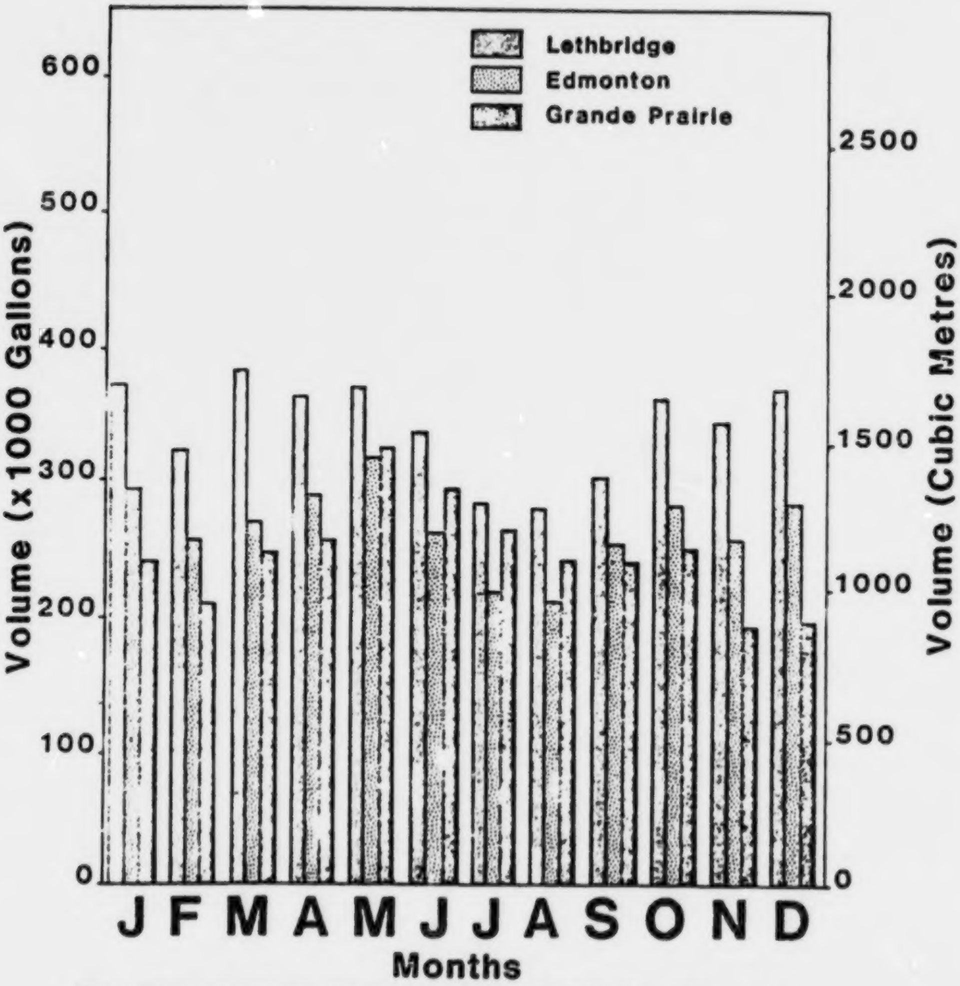
WIND BARON



EXPECTED VOLUME PUMPED AT 6 m LIFT

Figure 17

WILKES CAM



EXPECTED VOLUME PUMPED AT
6 m LIFT

Figure 18

MAVERICK MILL
PUMPING PERFORMANCE

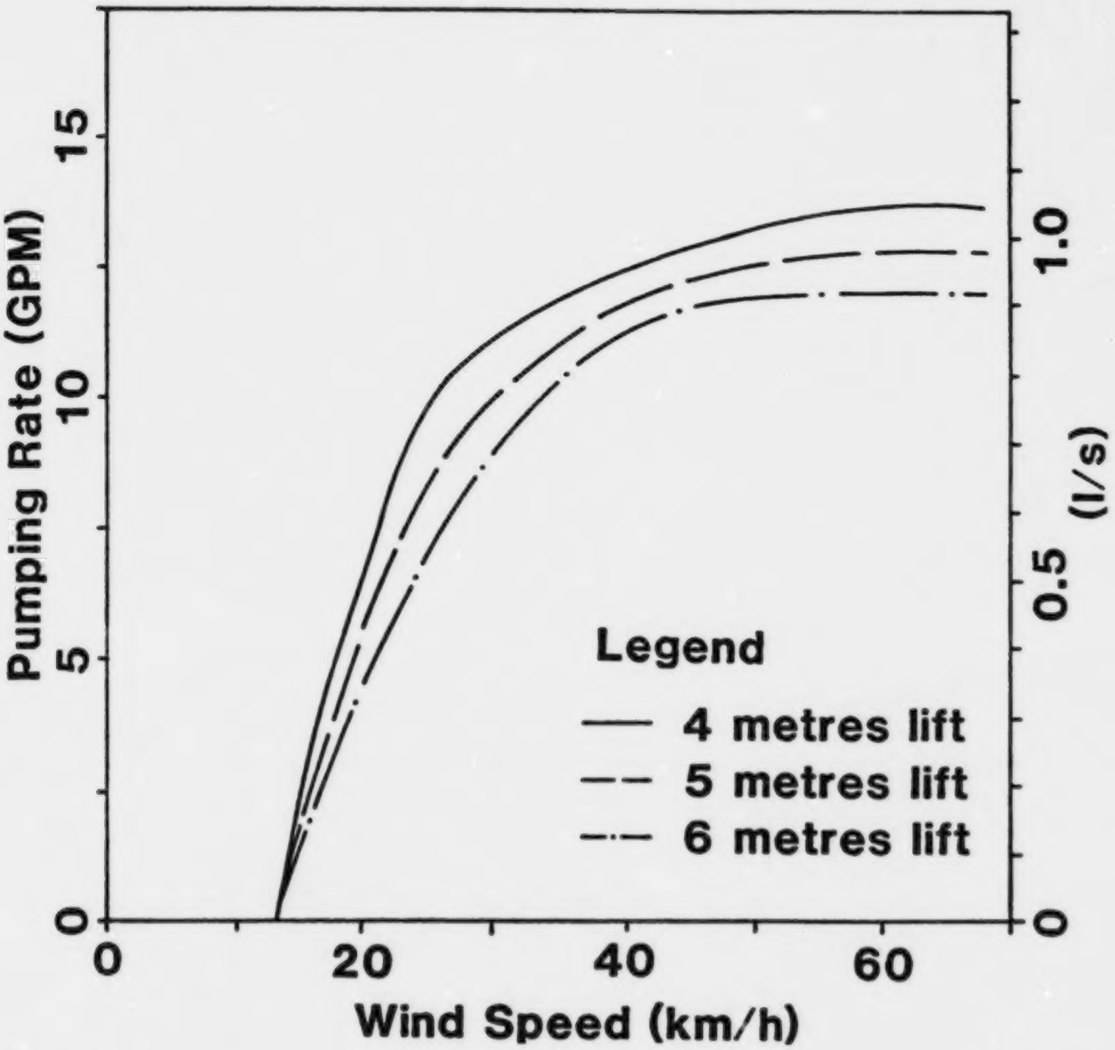
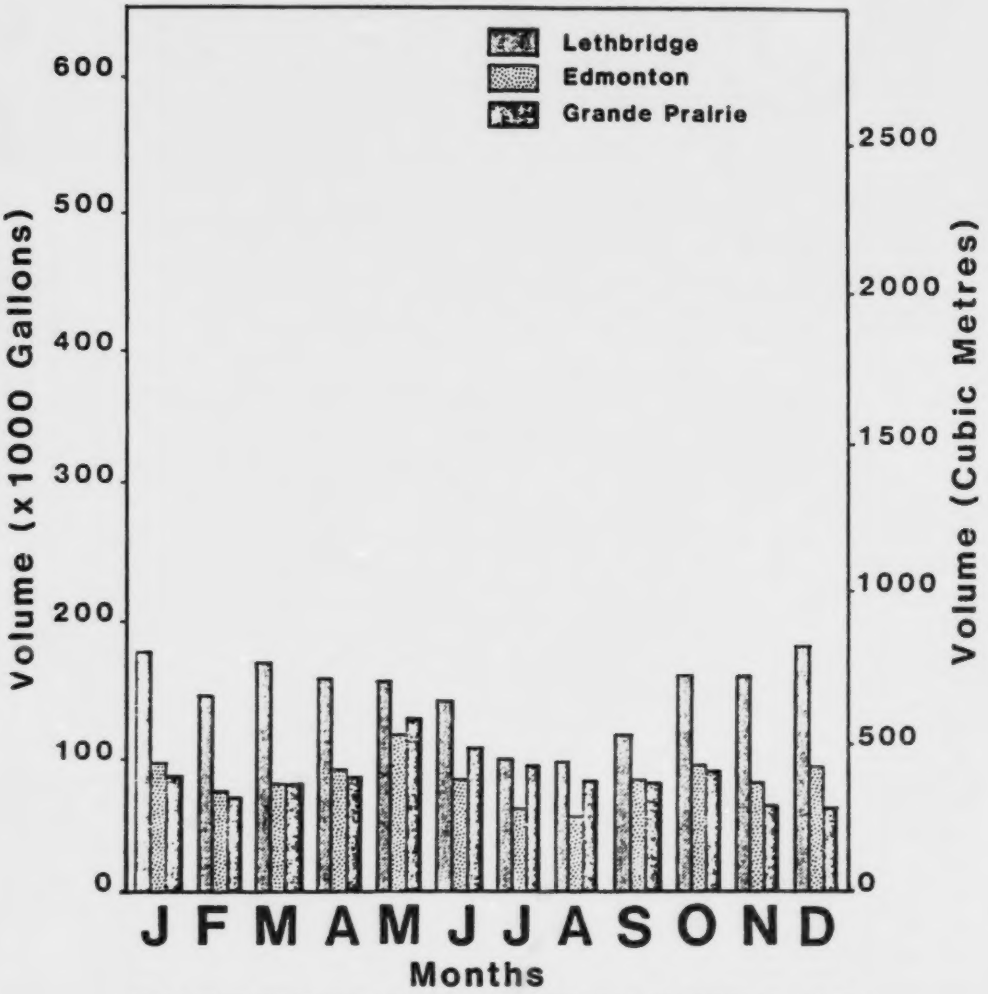


Figure 19

MAVERICK



EXPECTED VOLUME PUMPED AT

6 m LIFT

Figure 20

BOWJON PUMPING PERFORMANCE

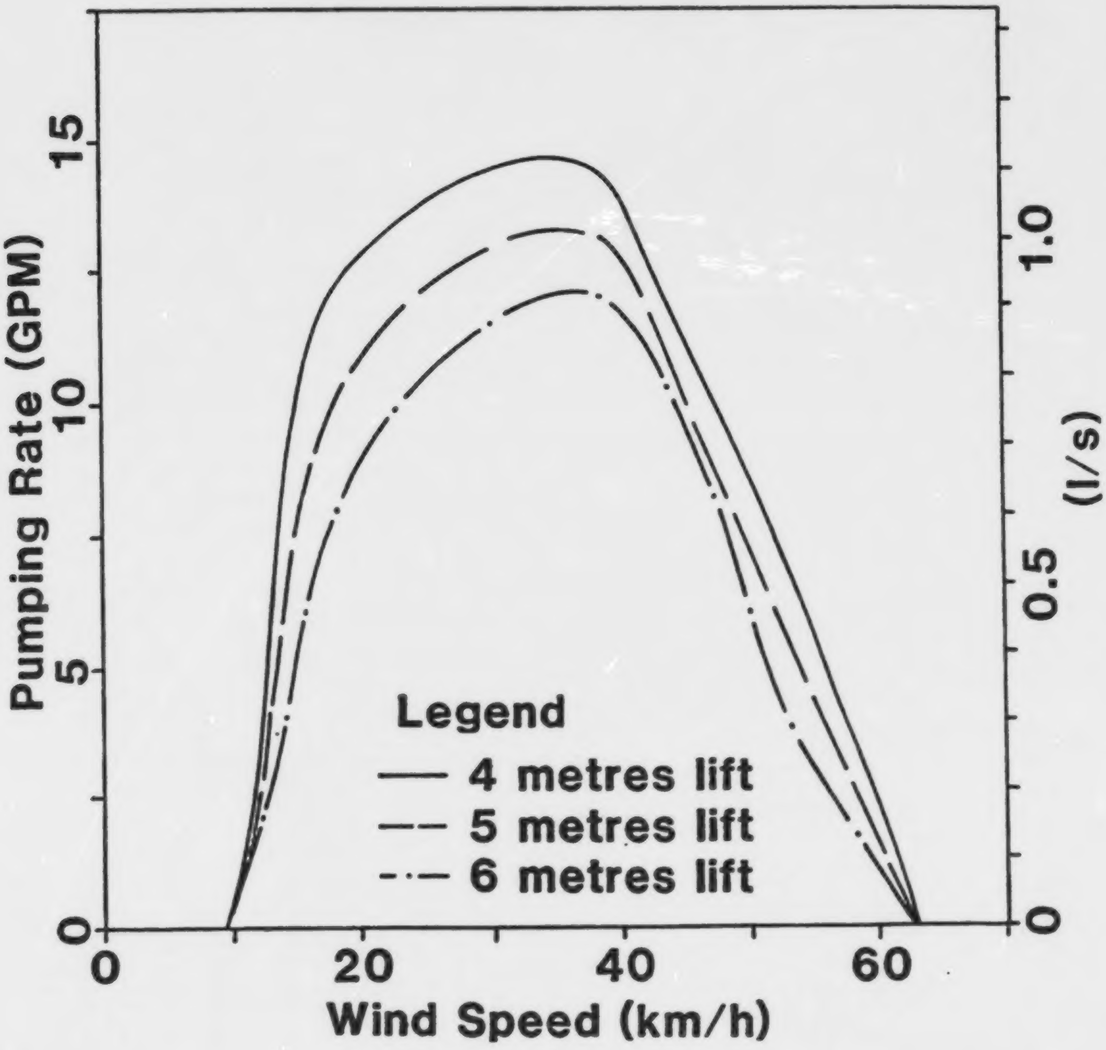
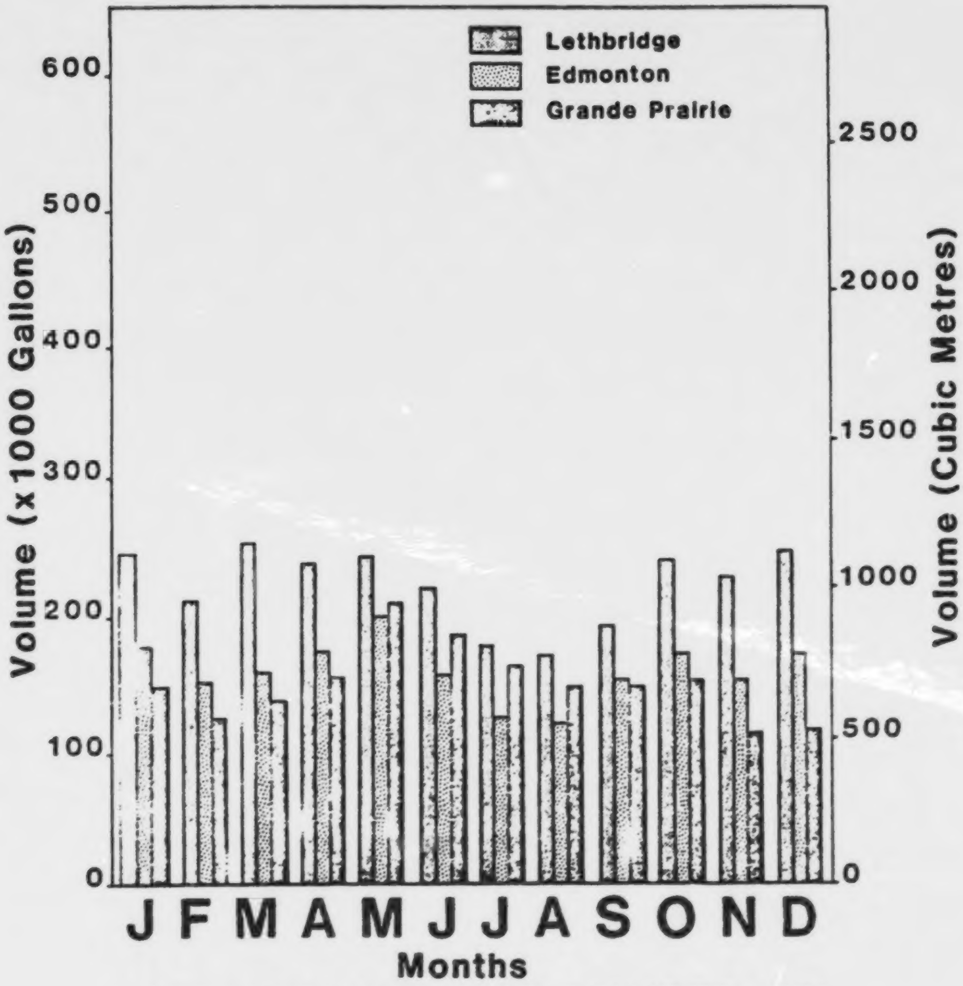


Figure 21

BOWJON



EXPECTED VOLUME PUMPED AT

6 m LIFT

Figure 22

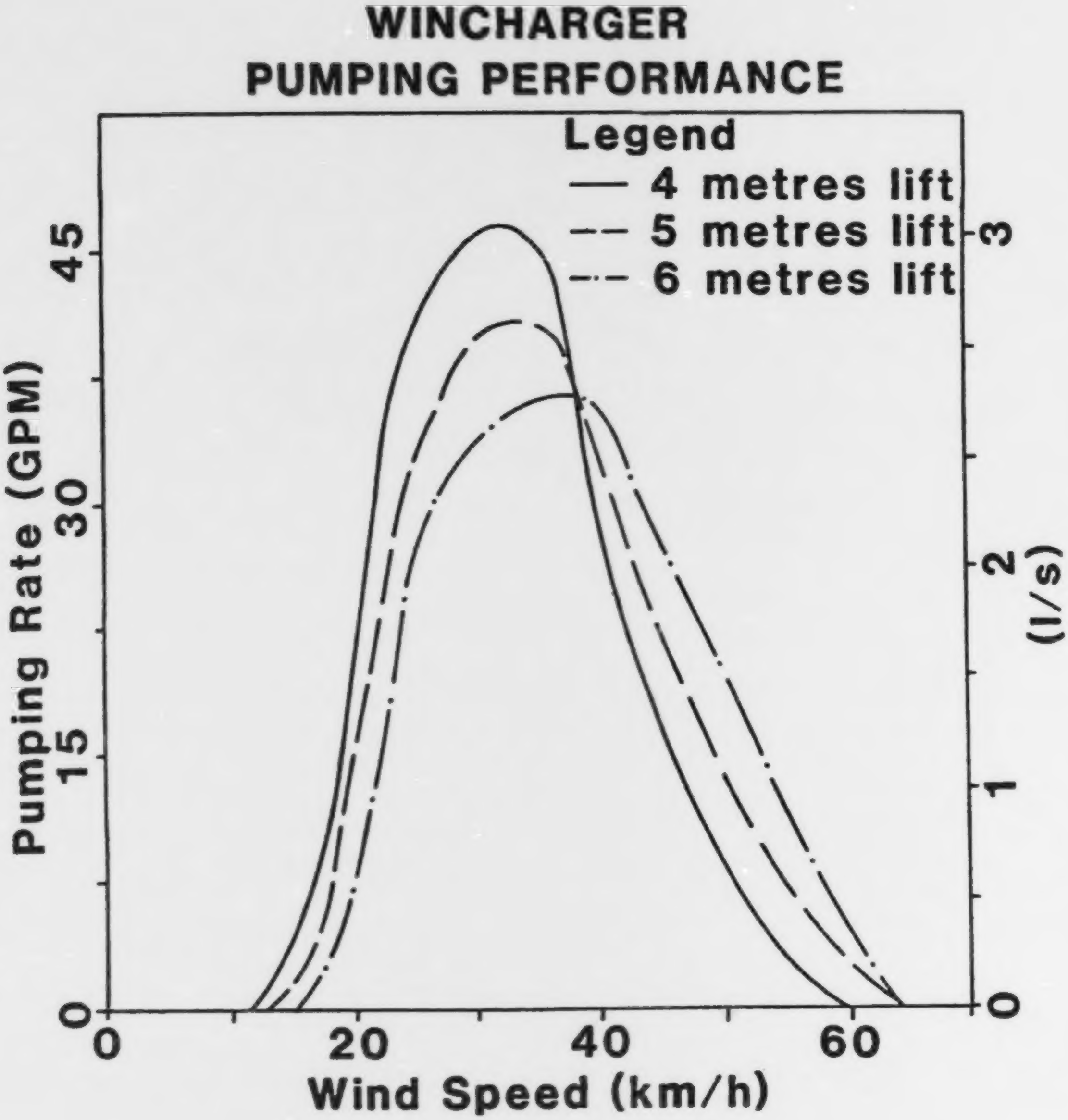
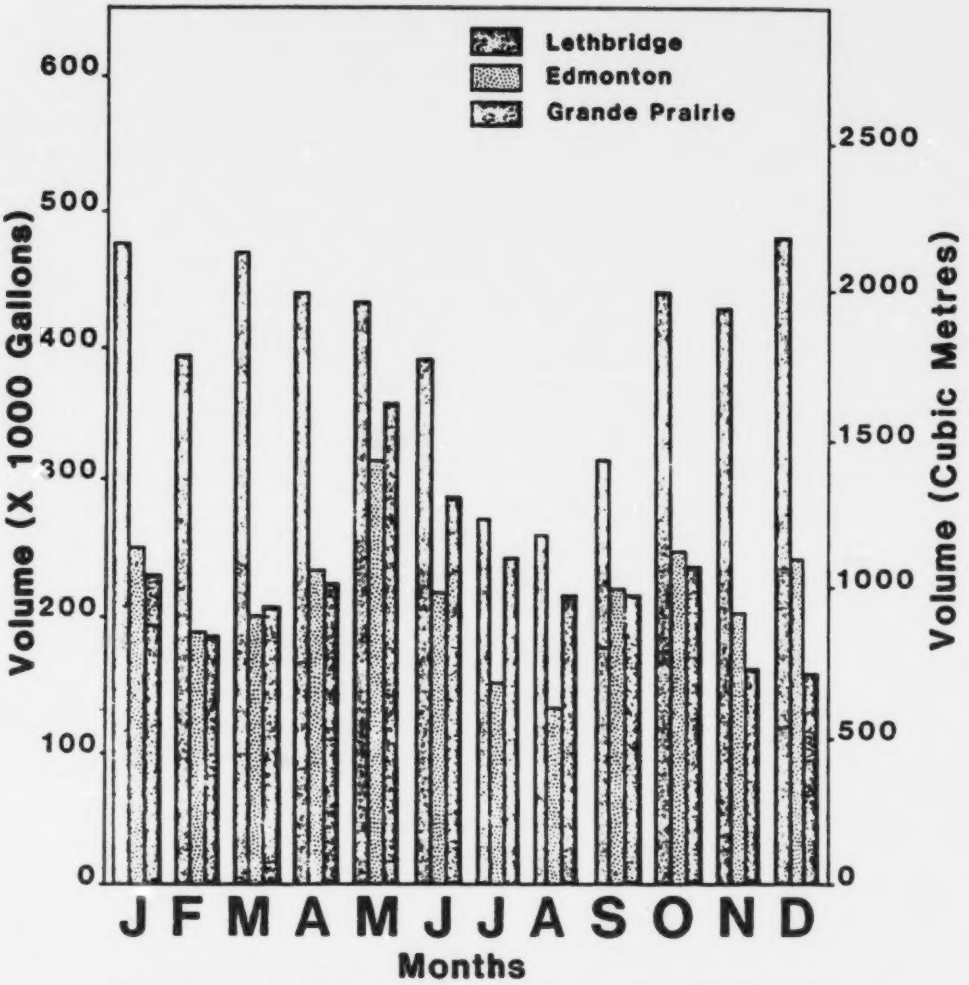

WINCHARGER
PUMPING PERFORMANCE
Legend
4 metres lift
5 metres lift
6 metres lift
Pumping Rate (GPM)
0
15
30
45
(l/s)
0
1
2
3
Wind Speed (km/h)
0
20
40
60

Figure 23

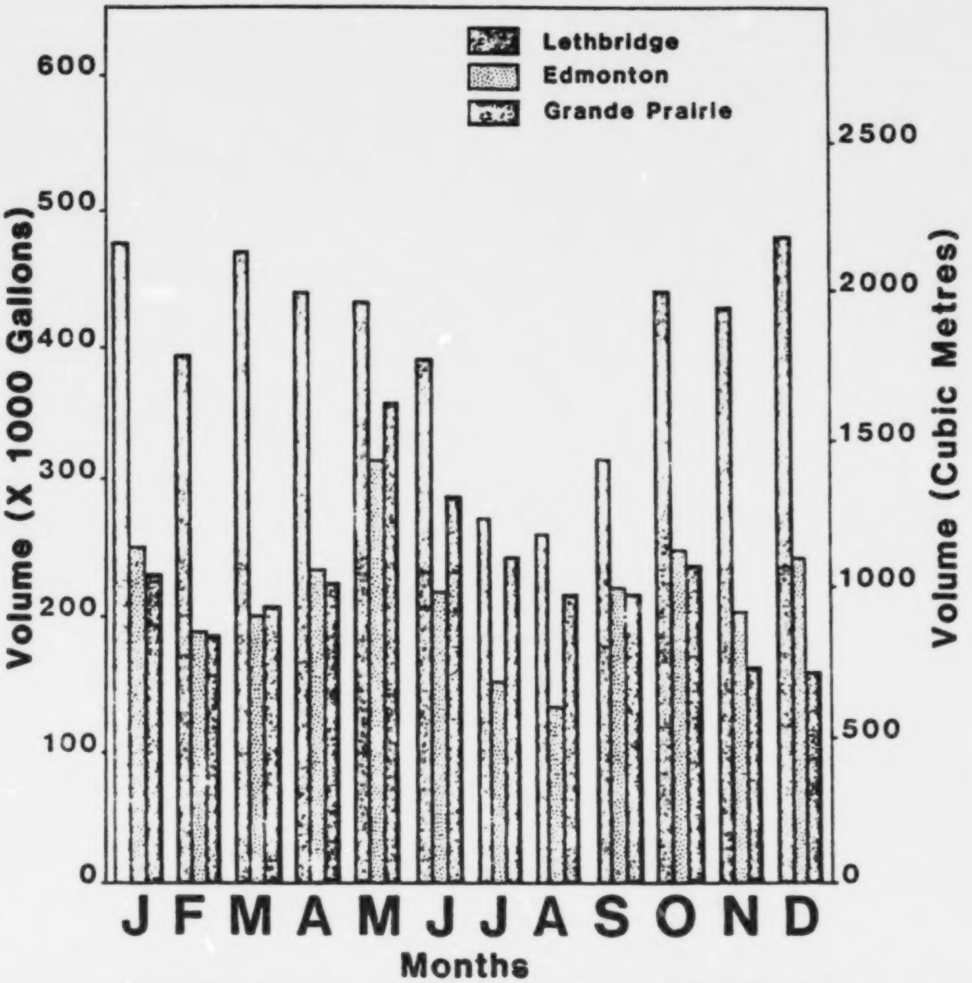
WINCHARGER



EXPECTED VOLUME PUMPED AT
6 m LIFT

Figure 24

WINCHARGER



EXPECTED VOLUME PUMPED AT

6 m LIFT

Figure 24

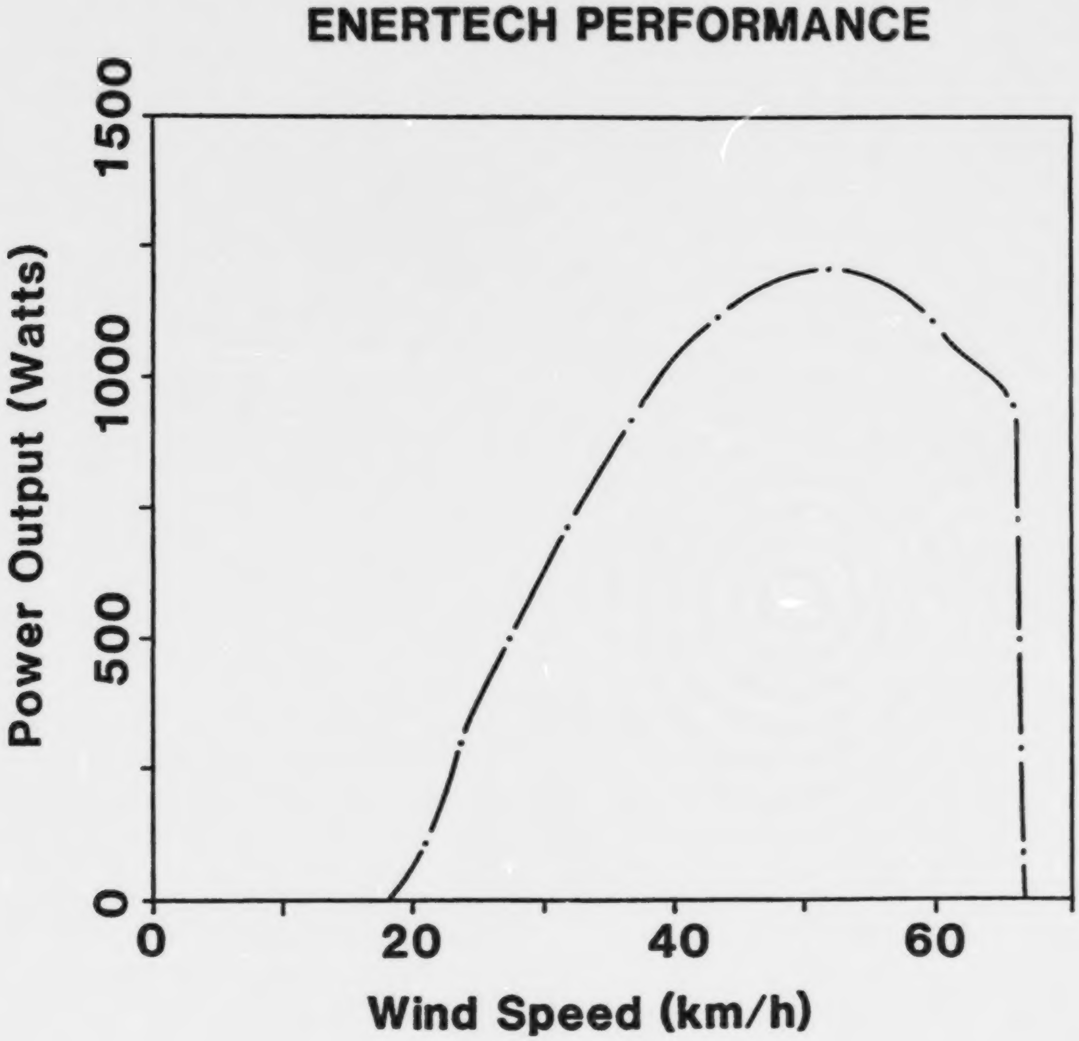
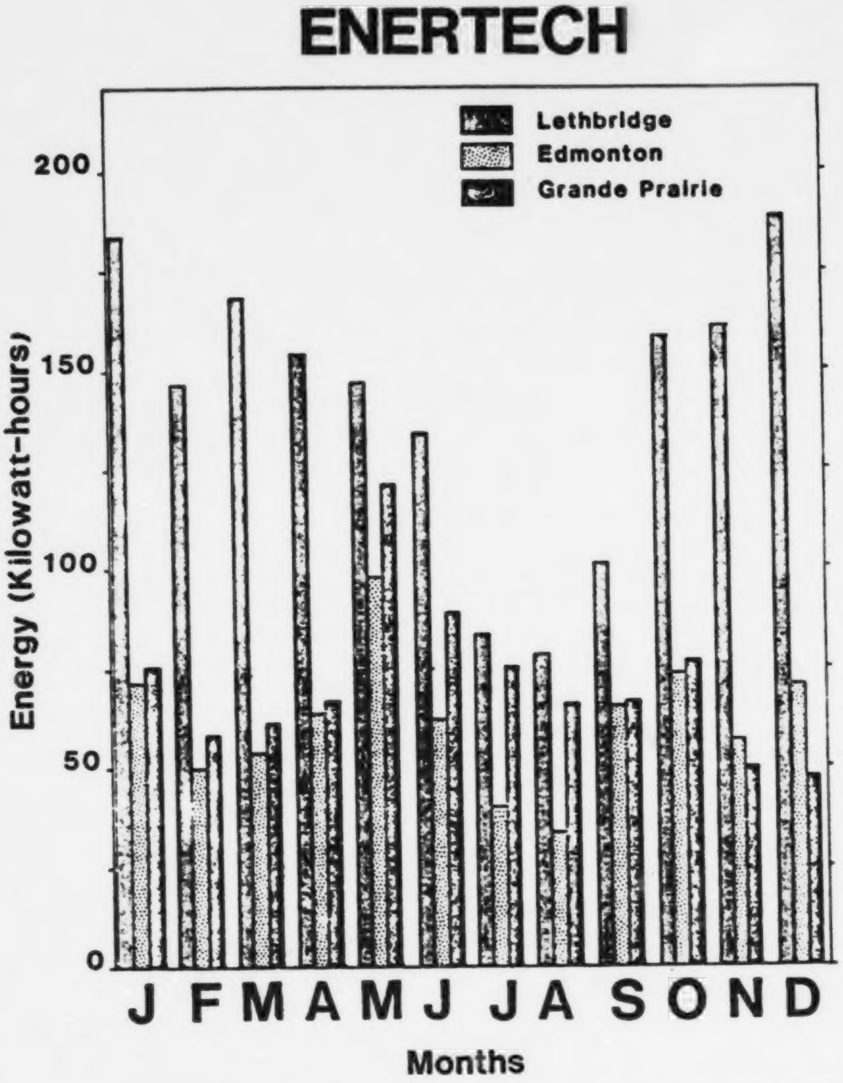

ENERTECH PERFORMANCE
Power Output (Watts)
0
500
1000
1500
0
20
40
60
Wind Speed (km/h)

Figure 25



EXPECTED MONTHLY ENERGY OUTPUT

Figure 26

TABLE 3. COMPARISON OF WINDPUMP CAPACITIES AND PUMPING COSTS

WIND PUMP	ANNUAL CAPACITY LETHBRIDGE (m^3)	CAPITAL COST (INSTALLED)	AMORTIZED AN. COST 25-YR. LIFE - 12% INTEREST	O & M (2½%)	COST PER m^3	ELECTRIC INSTALLATION TO PUMP EQUIVALENT VOLUME					
									AMORTIZED ANNUAL COST PER m^3		
						H.P.	Hours/year	kWh	1 km Line	2 km Line	3 km Line
Maverick	7 964.80	$ 3 500.00	$ 446.25	$ 87.50	$ 0.067	1/4	2050	390	$0.172	$0.284	$0.396
Bowjon	12 097.00	$ 3 500.00	$ 446.25	$ 87.50	$ 0.044	1/4	3120	600	$0.114	$0.188	$0.262
Wilks	18 606.00	$ 9 000.00	$1,147.50	$ 225.00	$ 0.074	1/4	5000	950	$0.075	$0.123	$0.171
Graham	21 109.00	$ 7 500.00	$ 956.25	$ 187.50	$ 0.054	1/4	5400	1,026	$0.067	$0.109	$0.151
Wincharger	21 744.00	$ 6 000.00	$ 756.00	$ 150.00	$ 0.042	1/4	5600	1,064	$0.065	$0.106	$0.147
Wind Baron	130 817.00	$19 000.00	$2 422.50	$ 475.00	$ 0.022	3/4	8760	5,000	$0.012	$0.019	$0.026

NOTES

1) Cost of power line = $7 000/km
2) Wiring and sump (installed) = $1 000
3) Pump and controls (installed) = $1 200
4) Life expectancy of pump = 10 years
5) Interest rate = 12%
6) Electricity Rate = $0.053/kWh
7) Service Charge = $10.00/month
8) Power consumption estimated from manufacturers pump literature

COMPARISON OF WIND PUMP CAPACITIES AND PUMPING COSTS

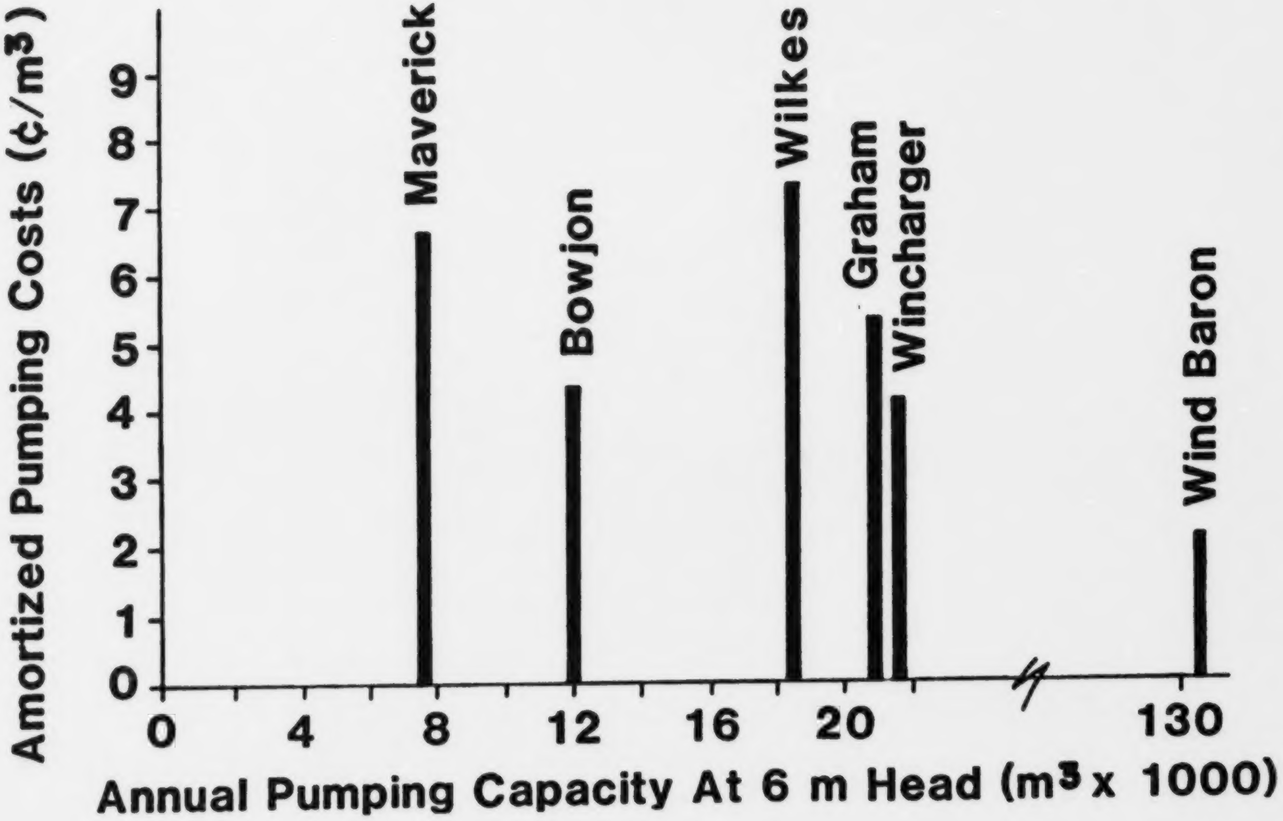
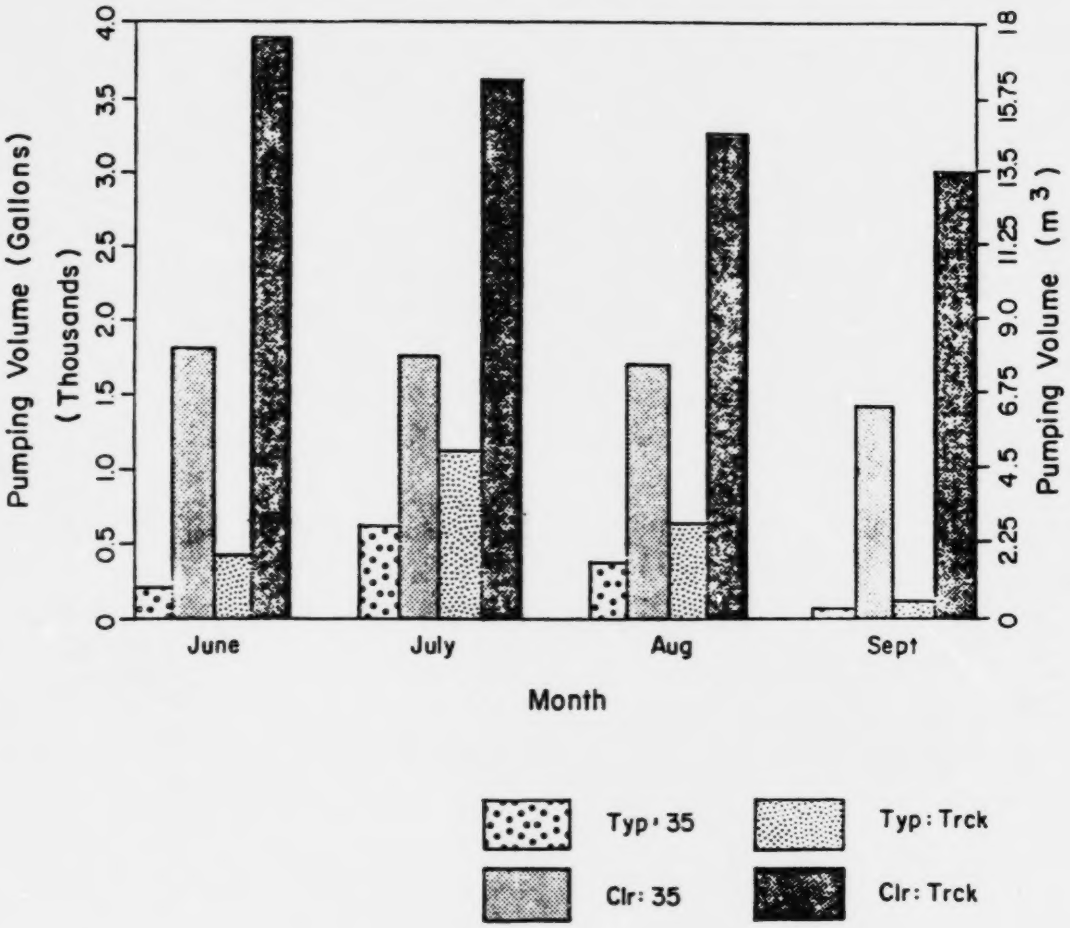


Figure 27

DAILY PUMPING VOLUMES FOR CAMBRIAN SOLAR UNIT AT 6 M LIFT



Typ: 35 - a typical day with the solar panels set at an angle of 35 degrees

Clr: 35 - a clear day with the solar panels set at an angle of 35 degrees

Typ:Trck - a typical day with the solar panels tracking the sun

Clr:Trck - a clear day with the solar panels tracking the sun

Figure 32

TABLE 4 ECONOMIC COMPARISON OF WINDPUMPS AND UTILITY POWER WITH SUBSIDIZED ELECTRICAL INSTALLATIONS

PUMPING APPLICATIONS	Example 1 Livestock Watering		Example 2 Drainage	
UTILITY POWER				
Power Required	1/4 h.p.		3/4 h.p.	
Annual Use	100 kWh		1,000 kWh	
Distance from Power Line	3 km		3 km	
Installation Cost	$21 000		$21 000	
Minus Grant	-10 500		-10 500	
Net Cost to Farmer	10 500		10 500	
		Annual Cost		Annual Cost
Amortized Annual Cost (25 yr. @ 3½%)		637		637
Wiring & Service Entrance ($1,000 amortized @ 12% over 25 yrs.)		128		128
Electricity Cost/Yr @ 5.3¢/kWh		5		53
Service Charges ($10/month)		120		120
Pump (installed capital cost)	1 200		1 400	
*Amortized Annual Cost for Pump (10 yrs. @ 12%)		212		248
TOTAL ANNUAL COST		1 102		1 186
WINDPUMPING SYSTEM				
Equipment (turbine, tower & pump)	3 500		7 500	
Installation	1 000		1 000	
Storage	1 000 (tank)		1 500 (dugout)	
TOTAL SYSTEM COST	5 500		10 000	
		Annual Cost		Annual Cost
Amortized annual cost (25 yr. @ 12%)		701		1 275
Operation & Maintenance (2½%)		138		250
TOTAL ANNUAL COST		839		1 525

*Assumed 10-year life and financing @ 12%

TABLE 5 ECONOMIC COMPARISON OF WINDPUMPS AND UTILITY POWER WITHOUT SUBSIDIZED ELECTRICAL INSTALLATIONS

PUMPING APPLICATIONS	Example 1 Livestock Watering		Example 2 Drainage	
UTILITY POWER				
Power Required	1/4 h.p.		3/4 h.p.	
Annual Use	100 kWh		1,000 kWh	
Distance from Power Line	3 km		3 km	
Installation Cost	$21 000		$21 000	
		Annual Cost		Annual Cost
Amortized Annual Cost (25 yr. @ 12%)		2 678		2 678
Wiring & Service Entrance ($1,000 amortized @ 12% over 25 yrs.)		128		128
Electricity Cost/Yr @ 5.3¢/kWh		5		53
Service Charges ($10/month)		120		120
Pump (installed capital cost)	1 200		1 400	
*Amortized Annual Cost for Pump (10 yr. @ 12%)		212		248
TOTAL ANNUAL COST		3 143		3 227
WINDPUMPING SYSTEM				
Equipment (turbine, tower & pump)	3 500		7 500	
Installation	1 000		1 000	
Storage	1 000 (tank)		1 500 (dugout)	
TOTAL SYSTEM COST	5 500		10 000	
		Annual Cost		Annual Cost
Amortized annual cost (25 yr. @ 12%)		701		1 275
Operation & Maintenance (2½%)		138		250
TOTAL ANNUAL COST		839		1 525

*Assumed 10-year life and financing @ 12%

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ATLANTIC WIND TEST SITE UPDATE

Carl Brothers

IMTSS 1985

INTRODUCTION

The Atlantic Wind Test Site (AWTS) is a national facility created by the governments of P.E.I. and Canada to assist in the development and testing of wind energy technology in Canada.

It is located at the extreme northern tip of P.E.I. at North Cape. It consists of 185 acres of flat terrain bordered by a low cliff and exposed through 300° to the Gulf of St. Lawrence.

The site is subjected to a wide range of weather conditions typical of the area as well as a moderately high rate of corrosion and salt spray.

Annual average winds of 6.25 m/sec (14 mph) are consistently higher in winter and prevail from the northwest in the winter and southwest in the summer.

The site was designed and developed by the Institute of Man and Resources (IMR) and is operated by IMR under a 10 year operating agreement with the National Research Council of Canada (NRCC).

IMR is a small local nonprofit organization that has been heavily involved in conservation and renewable energy studies for the past 10-12 years. Funding for the site is provided by paying clients and is supplemented by an annual contribution by NRCC to offset operating costs.

FACILITIES

For the site itself the earth sheltered lab provides an operations centre for site activities. It houses office space, living accommodations for occasional visitor emergencies, electronics lab and data processing centre.

A mechanical shop, equipped for typical maintenance purposes, is located near the main building. Adjacent to this is an area loaned to the Department of Tourism during the summer to serve as an information centre to the many site visitors.

The test site is serviced by a 600 V 30 line running the length of the site to provide interconnection and instrumentation power to each of the test pads. The test pads are generally located along this line and interconnect with the data system by underground fibre optic cable.

Each site has a small building housing switching equipment and a 280 based instrumentation processor to transmit pertinent data to the central computer.

A 50 meter met tower monitors meteorological conditions continuously.

The heart of the data acquisition system is a Perkin Elmer Interdata 816 116 bit computer. It is equipped with dual disc drives for active data storage and a tape drive for long term storage. This data processor is connected by fibre optics to a field located communications processor located at the base of the met tower. The CP is connected by fibre optic cable to each instrumentation processor at the individual sites. The CP collects data from each active IP, up to 16 parameters each, and transmits this data once per second to the data processor in the main lab for storage on disc. Once every several days the data is transferred to tape for permanent storage or reduced to appropriate averages for additional data manipulation on the site's HP9845B microcomputer.

Site personnel provide all maintenance and most software generation for on site testing.

PROJECTS

Several projects at the AWTS have been ongoing for several years on equipment that is permanently located at the site.

Bergey

The 1 kW Bergey was moved to the site several years ago when a local demonstration project on an autonomous living environment was completed. It was originally used as a battery charger on an acquaculture project. Since coming to AWTS it has been tested as a battery charger. Recently the controller failed and the machine is presently idle. However, we do have a synchronous inverter we plan to use to connect this machine to the grid.

9 x 6

The 9 x 6 m DAF Indal 7.5 kW VAWT was obtained from the same project. It was originally connected to a hydraulic pumping unit to provide greenhouse heat. When erected at the site it was fitted with a speed increaser, induction motor/generator with integral electric brake. It has been used as part of a telemetry project and is available for future tests. It is presently supplementing site electrical requirements.

In addition to these ongoing projects we have four active projects at AWTS.

AES Anemometer Comparison

Anemometry equipment is available in a very wide price range ($35 - $1000). In an effort to determine any relationship between price, performance and reliability, the AWTS in conjunction with AES has been testing 16 anemometers and histogram recorders over roughly a one year period to compare 10 minute averages of wind measurements.

The test has been concluded and the interpreting of results is underway.

Northwind

Health and Welfare Canada purchased a L916 - 16 kW HAWT for installation in Hall Beach, NWT.

Prior to installation it was agreed a 12 month test at AWTS would be beneficial to evaluate performance in a rigourous marine environment.

The downwind machine has a two bladed 9 m diameter rotor with passive pitch control.

A synchronous generator rotates at 150 rpm. Tests are continuing.

Aquilo

The largest machine on site is a 500 kW DAF Indal series 6400 VAWT.

Rated at 522 kW at 42.5 mph it has a rotor 36 m x 24 m (120 x 80 ft), and rotates at 45 rpm. This drives two 350 HP induction generators through a 16:1 spur gear single mesh speed increaser.

The unit has been extensively instrumented to provide dynamic structural data. A total of 56 signals may be monitored by a HP 1000 based computer system in the control shed.

Software for data reduction and analysis originated with Sandia and modified by NRCC.

Adecon 125 VAWT

NRCC has commissioned Adecon Energy Corp. of Toronto to develop a low cost intermediate size VAWT.

The result is a free standing unit with a 25 m x 17 m rotor sitting 12 meters above ground level, supported by a lattice work of angle sections.

This lattice frame reduces bearing and torque tube sizes substantially as well as foundation and space requirements while increasing energy production from the raised rotor.

The lightweight aluminum blade has a 24" chord and weighs ≈10 lbs./ft. It rotates at 45 rpm and is connected through a 40:1 speed increaser to an induction motor/generator.

Adecon staff are presently conducting tests on the unit and completing the controls system before a fully operational test begins.

FUTURE

Recent cut-backs by the Canadian government have eliminated the Division of Energy at NRCC by late 1986. This removes NRCC, which has been until now the driving force for wind energy development in Canada, as a participant in further wind energy work. The Department of Energy, Mines and Resources has received some funding to continue wind energy research and development but at a substantially reduced rate.

The result will inevitably be reduced activity in the Canadian wind energy industry and continued operation at the site based solely on testing windmills will be difficult. We may have to broaden our range to cover more areas of environmental testing or to participate in a wider range of wind energy activities such as product development or applied research.

In the wind energy testing context we do have some potential projects developing:

We hope to continue testing Aquilo to determine longer term operational characteristics.

We are discussing possibilities for participating with Adecon in further developing their wind energy system.

There is widespread interest in Canada in a broader application of a wind diesel hybrid system and we are confident that a system will be installed at the site at some time in the future.

With the completion of the Canadian Standards, the AWTS is one of the few places equipped to certify equipment. We hope to conduct a test in the near future to verify the performance section of this standard.

We are presently proposing a cost reduction study for windmills in a Canadian context.

In addition to these possibilities we hope to provide a continuing contribution where we can to the overall development of the wind energy development program in Canada in a way that our accumulated expertise is fully utilized.

SUMMARY

Wind energy research and development in Canada faces some uncertainty at present due to the removal of NRCC participation and the future direction under EMR not yet well defined. Early input from EMR indicates interest in continued operation of the site and with the smaller program in Canada the AWTS may play a more significant role than at present. Until the future becomes better defined we continue attempts to sell our expertise to any potential client and await further development with cautious optimism.

An Aerogenerator Testing Facility at IREQ

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ABSTRACT

The aim of the aerogenerator testing facility at IREQ is to provide a broad reliable data base for validating simulation models currently under development at the Institute. The test program covers the dynamic characteristics of the wind turbine: the guy wires and the mechanical and electrical drive train under various loading conditions, both steady-state and transient. The machine under investigation is a commercial vertical-axis wind turbine modified to allow operation at variable speeds, with a three- or six-guy wire support at adjustable tension levels. The instrumentation, the electrical wiring and the data acquisition and processing system of the installation are described. The test program and typical test results (parametric resonance) are presented and discussed.

KEYWORDS

Experimental vertical-axis wind turbine, static-frequency converter, guy-wire vibration, power-train dynamics, parametric resonance, instrumentation.

INTRODUCTION

Since 1976, IREQ's activities in wind energy research have been oriented mainly towards vertical-axis wind turbines (VAWT), a concept in which Canadian scientists are strongly interested. A new test facility has recently been built at the Institute which can be used for both vertical- and horizontal-axis machines. Interesting results have already been obtained for a series of tests done on a VAWT. The experience gained at the Magdalen Islands test site proved very useful when planning this facility.

DESCRIPTION OF SITE AND MACHINE

The Varennes site is well exposed to the prevailing westerly winds. The average annual wind speed is 4.7 m/s at a height of 10 m and the average hourly windspeed exceeds 5.5 m/s 36% of the time.

Installed in July 1983, the machine is manufactured by DAF INDAL Ltd. of

Mississauga, Ontario, with a few modifications for the purpose of the tests (three or six guy wires, and variable-speed operation). The rotor is 17.5 m high, 11.2 m in diameter, and has two aluminum extruded blades with a NACA 0015 profile, and a chord of 0.36 m. Three different asynchronous electrical machines can be connected directly to the high-speed shaft:

1. one squirrel cage machine, whose stator is directly connected to the network transformer (nominal configuration);
2. one wound-rotor motor capable of driving the low-speed shaft up to 100 rpm
(freewheeling only in zero wind conditions);
3. one wound-rotor machine, used in drive or generation mode. This machine has a synchronous speed of 720 rpm and will absorb power from the low-speed shaft over the range from 47 to 95 rpm.

The two latter machines are connected to the network via a static-frequency converter and permit operation of the system at variable speed, which is particularly useful for VAWT vibration and performance testing.

When the VAWT is in braked position, its low-speed gear rests on four braking shoes, while during operation, it and the rotor are lifted clear by means of a large hydraulic cylinder. The operating guy-wire tension can therefore be adjusted by suitably controlling the hydraulic pressure. This feature has an interesting advantage in that, once the pressure is set, the guy wire tension will not be affected by temperature variations.

INSTRUMENTATION

The aerogenerator is presently instrumented with 48 sensors located as shown

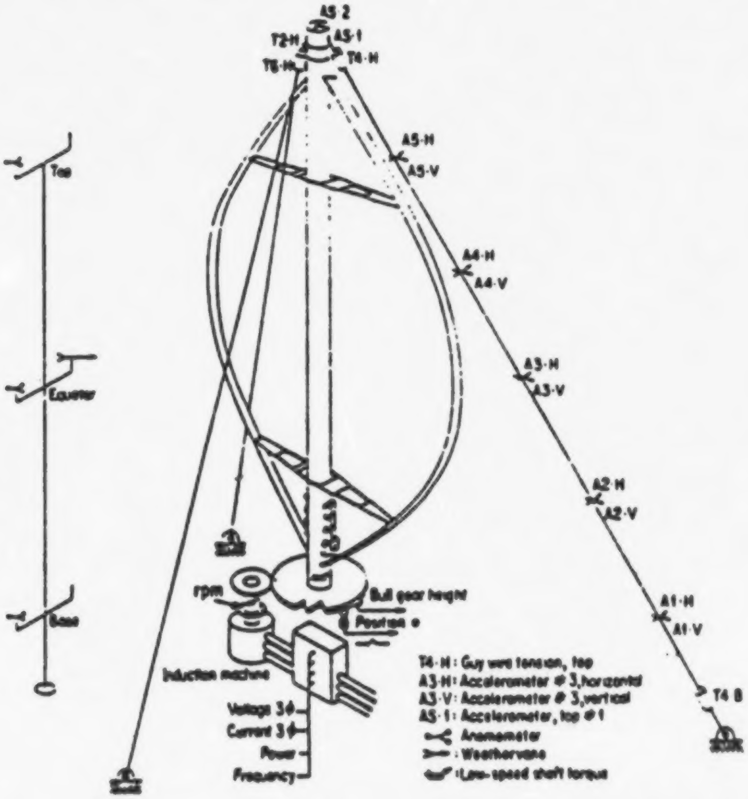

AS-2
T2-H
AS-1
T6-H
T4-H
AS-H
AS-V
Top
A4-H
A4-V
A3-H
A3-V
Equator
A2-H
A2-V
rpm
Bull gear height
Position
Base
A1-H
A1-V
Induction machine
Voltage 3ϕ
Current 3ϕ
Power
Frequency
T4 B
T4-H : Guy wire tension, top
A3-H : Accelerometer # 3, horizontal
A3-V : Accelerometer # 3, vertical
AS-1 : Accelerometer, top # 1
: Anemometer
: Weathervane
: Low-speed shaft torque

Fig. 1 Instrumentation of the Darrieus wind turbine at IREQ

in figure 1. All instrumentation wiring and signal transmission lines and shields have been devised from the point of view of maximizing the S/N ratio. The sensor power supplies and outputs are fed via underground iron ducts to the signal-conditioning cabinet and to the A/D converter in the laboratory control room. All measurement and control cables are grounded via the same copper sheathing (figure 2).

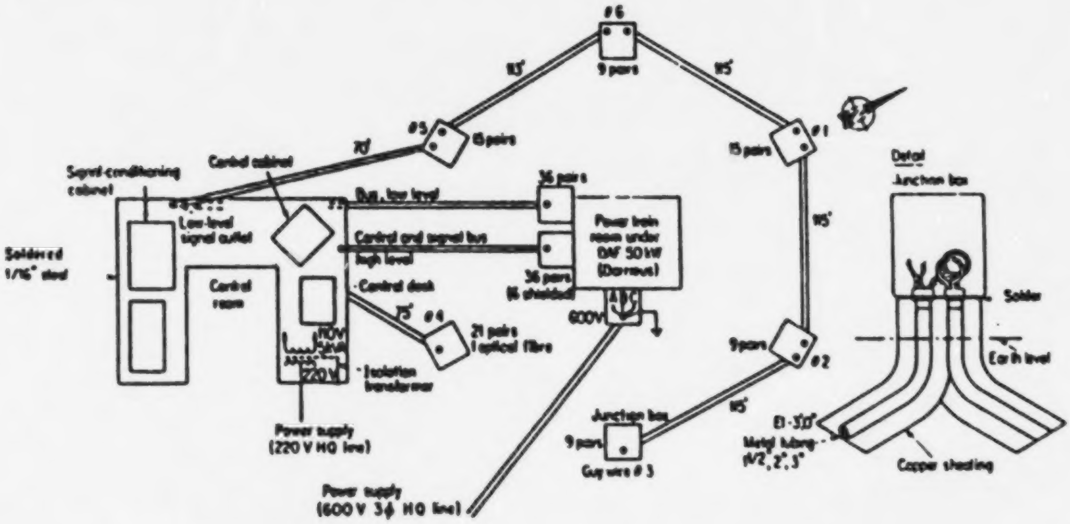

#6
9 pairs
115'
115'
#5
15 pairs
#1
15 pairs
70'
Control cabinet
Signal-conditioning cabinet
Low-level signal outlet
Bus, low level
36 pairs
Power train room under DAF 50 kW (Darrieus)
Control and signal bus high level
36 pairs (6 shielded)
Soldered 1/16" steel
Control room
Control desk
75'
#4
21 pairs (optical fibre)
110V
220V
Isolation transformer
600V
115'
9 pairs
#2
Power supply (220 V HQ line)
Junction box
9 pairs
Guy wire # 3
115'
Power supply (600 V 3ϕ HQ line)
Detail
Junction box
Solder
Earth level
El -3.0"
Metal tubing ϕ1/2", 2", 3"
Copper sheating

Fig. 2 Instrumentation, control and power supply network

DATA ACQUISITION AND PROCESSING

The data acquisition system has the following characteristics:

. Number of channels, N	1 to 24 ($N \neq 2$)
. Signal input level	± 10 V
. LSB A/D converter	4.88 mV
. Sampling rate, SR	4,760/N samp./s/chan.
. Test duration	15,360/(N·SR) sec.
. Samples per channel, n_p	15,360/N
. Min. frequency resolution, f with $n_e = (2^k \leq n_p)$, $k = 9, 10, 11$	$2SR/n_e$ Hz

It is built around a microNova MP200. Test data is temporarily stored on the peripheral disk unit. The software developed for this test site has been described elsewhere (Flamand, 1984). Software programs for data display on a graphic terminal permit analysis in both the time and the frequency domains while hard copies can be produced on an Okidata printer, at the user's command. All test results are transferred to diskettes and sent to the main computer room where they are stored on tape for more detailed processing and analysis on IREQ's central computer.

TEST PROGRAM

The experimental program focuses on the static and dynamic behavior of the rotor, the support structure, the power train, the control system stability and the environment of a VAWT (Léonard, 1983).

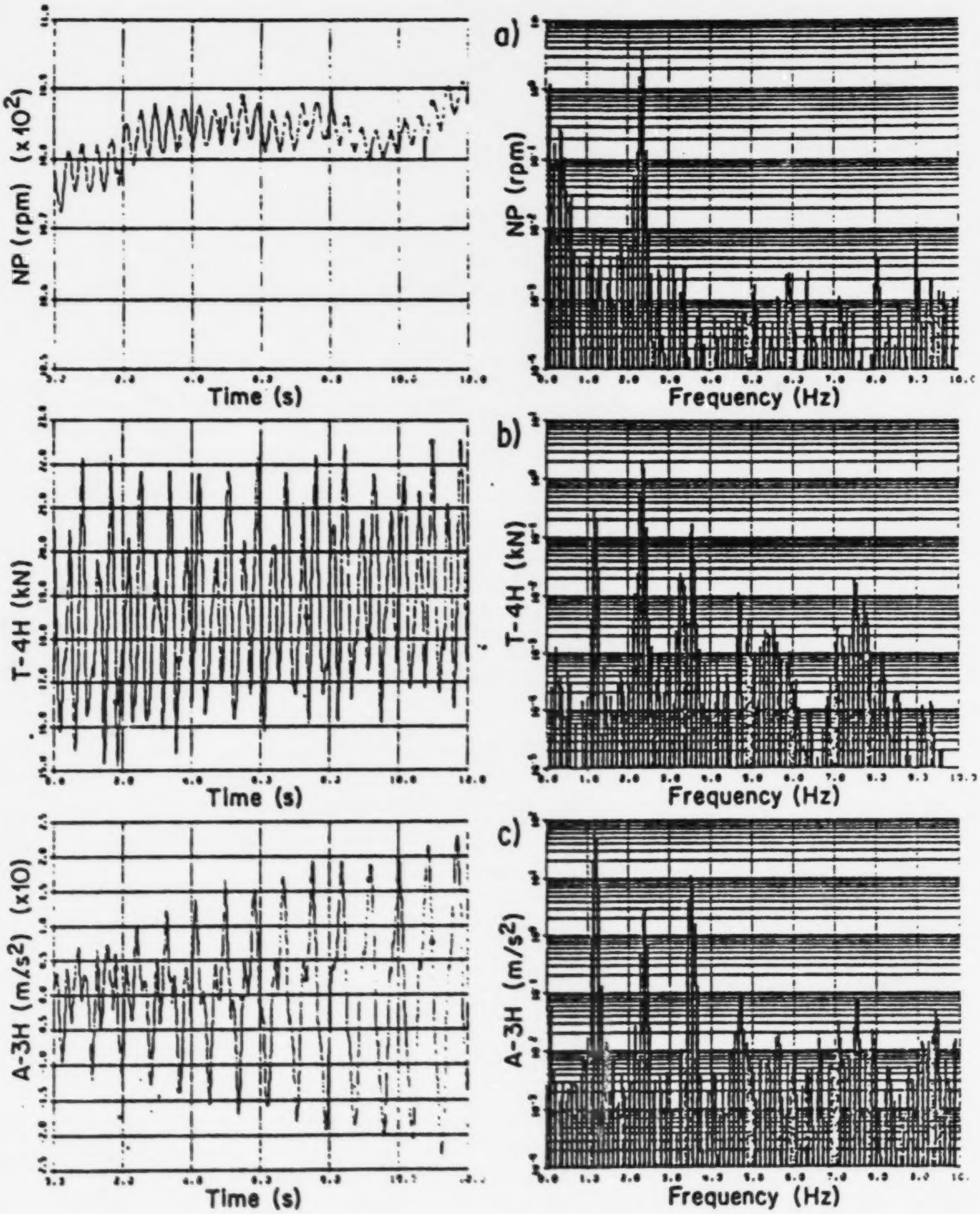


Fig. 3 Variations in parametric resonance with increasing rpm (vs time and frequency)

a) rpm

b) guy wire tension

c) horizontal-vibration level at mid-span of guy wire

EXPERIMENTAL RESULTS

As an example of the type of results collected, figure 4 illustrates a phenomenon known as parametric resonance, a situation which occurs when resonance of a structural member is induced by an excitation force having a frequency twice that of the resonant frequency. This example, recorded at a tip-speed ratio of 4.25 and an average wind speed of 10 m/s, shows the lateral vibration level recorded by an accelerometer located at mid-span of the guy wire, following an increase in the rpm reference setting. It is interesting to note the progressive change in the frequency content of the signal with time: the higher frequencies observed in the initial phase of the test gradually disappear in a strong vibration, indicating first-mode resonance of the guy wire at a frequency of 1P excitation, even though the 2P aerodynamic excitation is dominant throughout the test, as indicated by the simultaneously recorded rpm and guy wire tension signals.

Other test results presented by Pastorel and Beaulieu (1985) have supported the validation of a simulation model of the nonlinear vibration modes of the guy wire support system. More than 300 classified tests have been completed since the commissioning of this facility.

ACKNOWLEDGEMENT

The author expresses his gratitude to the members of the experimental team without whom the facility would never have come about. Thanks are due thus to Dorien Marois, Luc Martel, Yvon Vigneau, François Léonard and Réal Reid for their sustained cooperation and advice throughout the course of the project.

REFERENCES

Pastorel, H. and Beaulieu, G. (1985). Computers and Structures, 21, Nos. 1 and 2, 33-50
Pérocheau, A. (1984). Internal Report IREQ-8RT3061G.
Barry, A.O., Saulnier, B. Marois, D. (1985). Internal Report IREQ-8RT3276G.
Flamand, J. (1984). Internal Report IREQ-7RT3027G.
Léonard, F. (1983). Internal Report IREQ-2917.

PROJET
ÉOLE

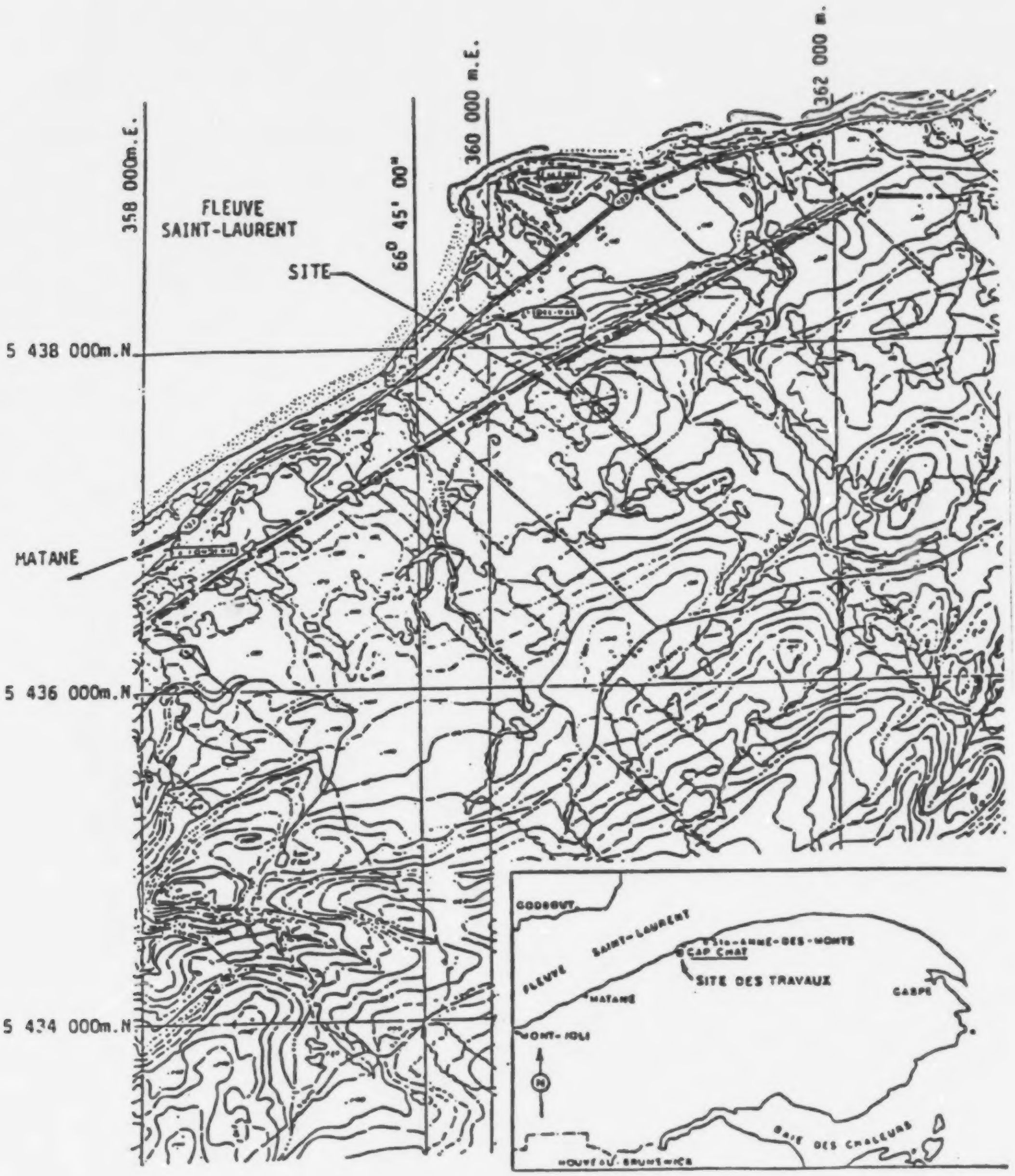
4 MW
WIND TURBINE
CAP-CHAT

JACQUES PLANTE
NATIONAL RESEARCH COUNCIL
CANADA

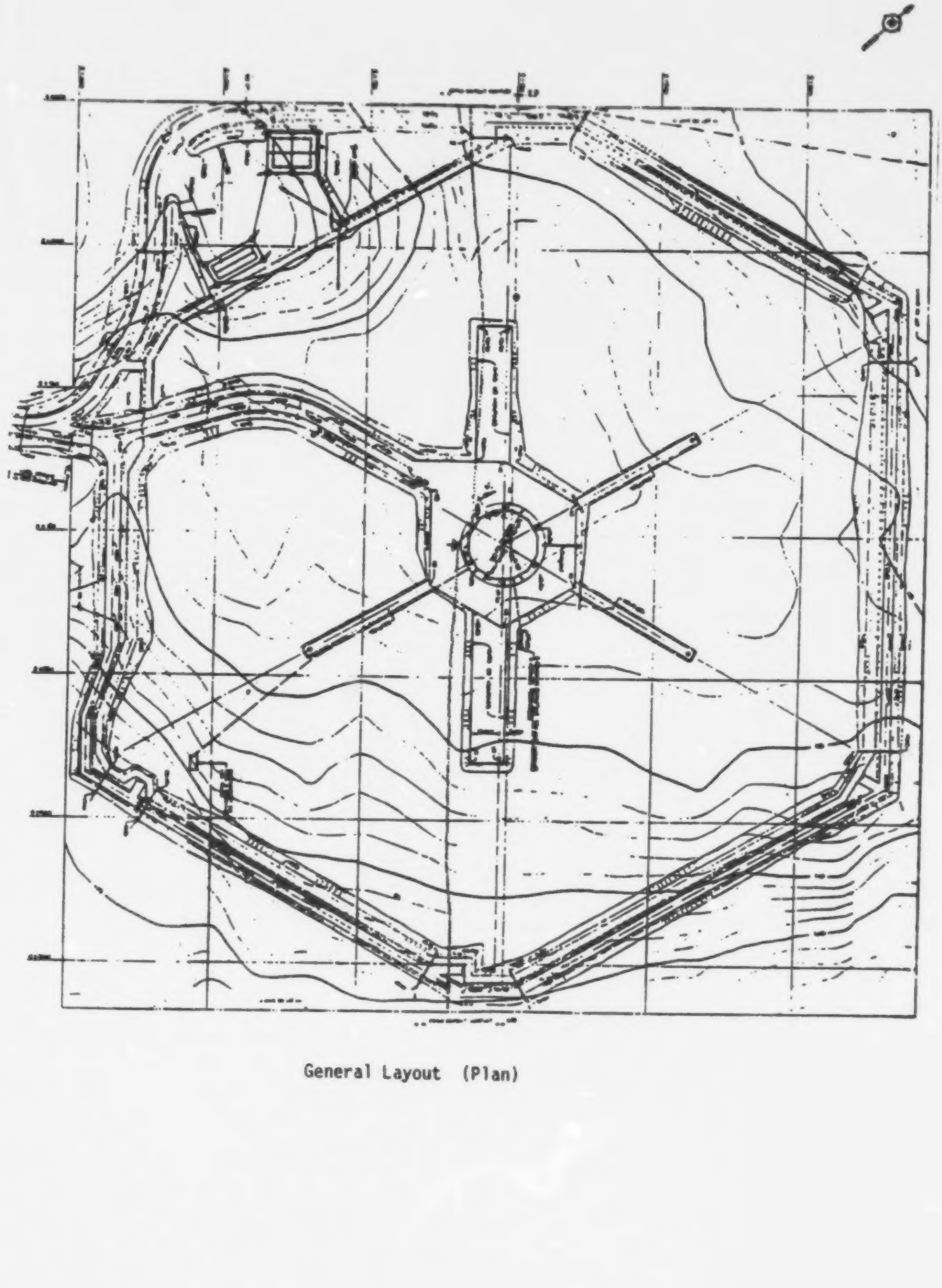
PROJECT EOLE

Project Eole is a cooperative, cost-shared undertaking by Hydro-Quebec and the National Research Council of Canada to design, build and evaluate a prototype multimegawatt-scale Darrieus wind turbine.

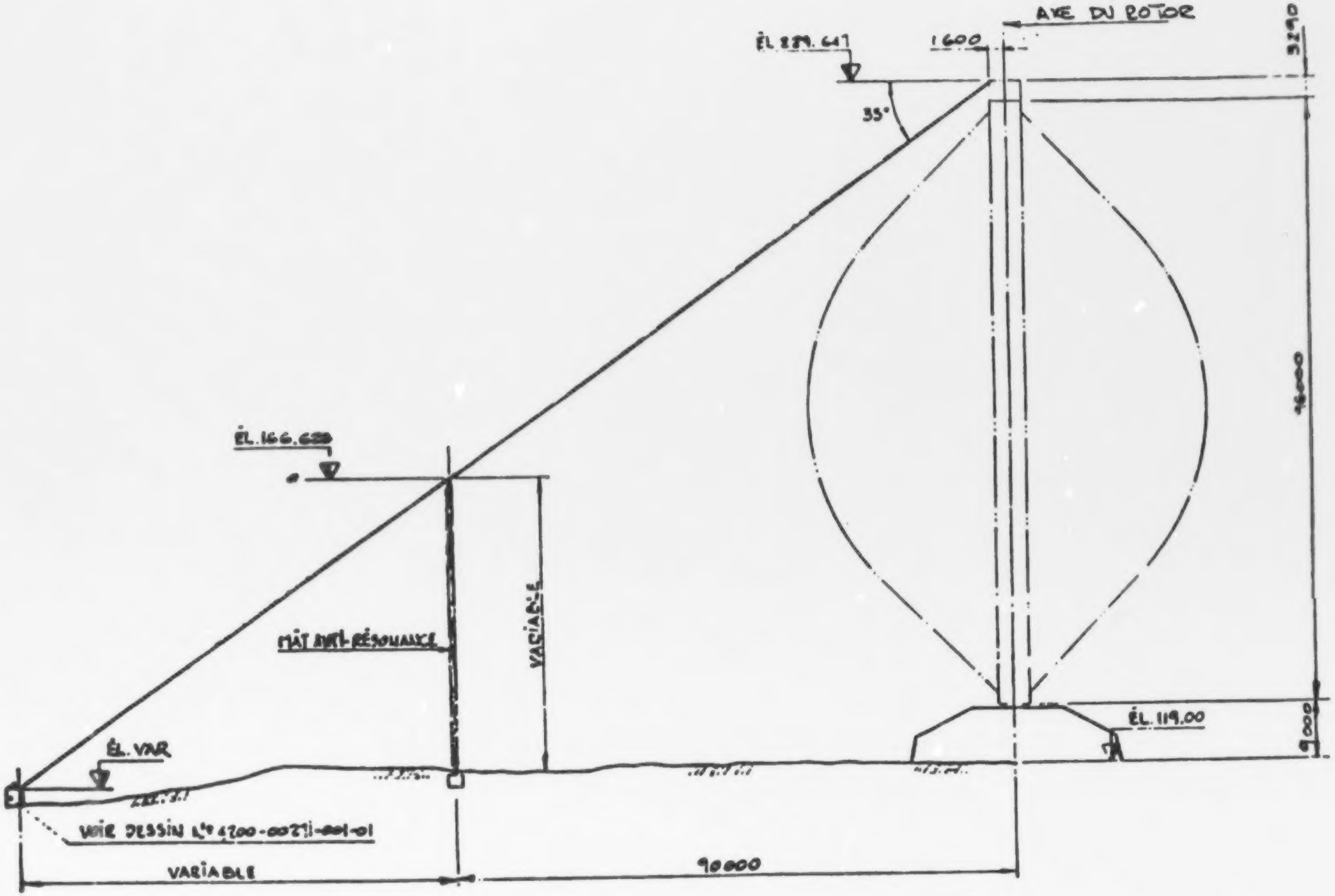
The following figures show the location, arrangement, general configuration, power train, electrical system one line diagram, data acquisition system interconnection diagram and a revised schedule.


358 000m.E.
FLEUVE SAINT-LAURENT
66° 45' 00"
360 000 m.E.
362 000 m.
SITE
5 438 000m.N
MATANE
5 436 000m.N
5 434 000m.N
GODBOUT
FLEUVE SAINT-LAURENT
STE-ANNE-DES-MONTS
CAP CHAT
SITE DES TRAVAUX
MATANE
GASPE
MONT-JOLI
N
BAIE DES CHALEURS
NOUVEAU-BRUNSWICK

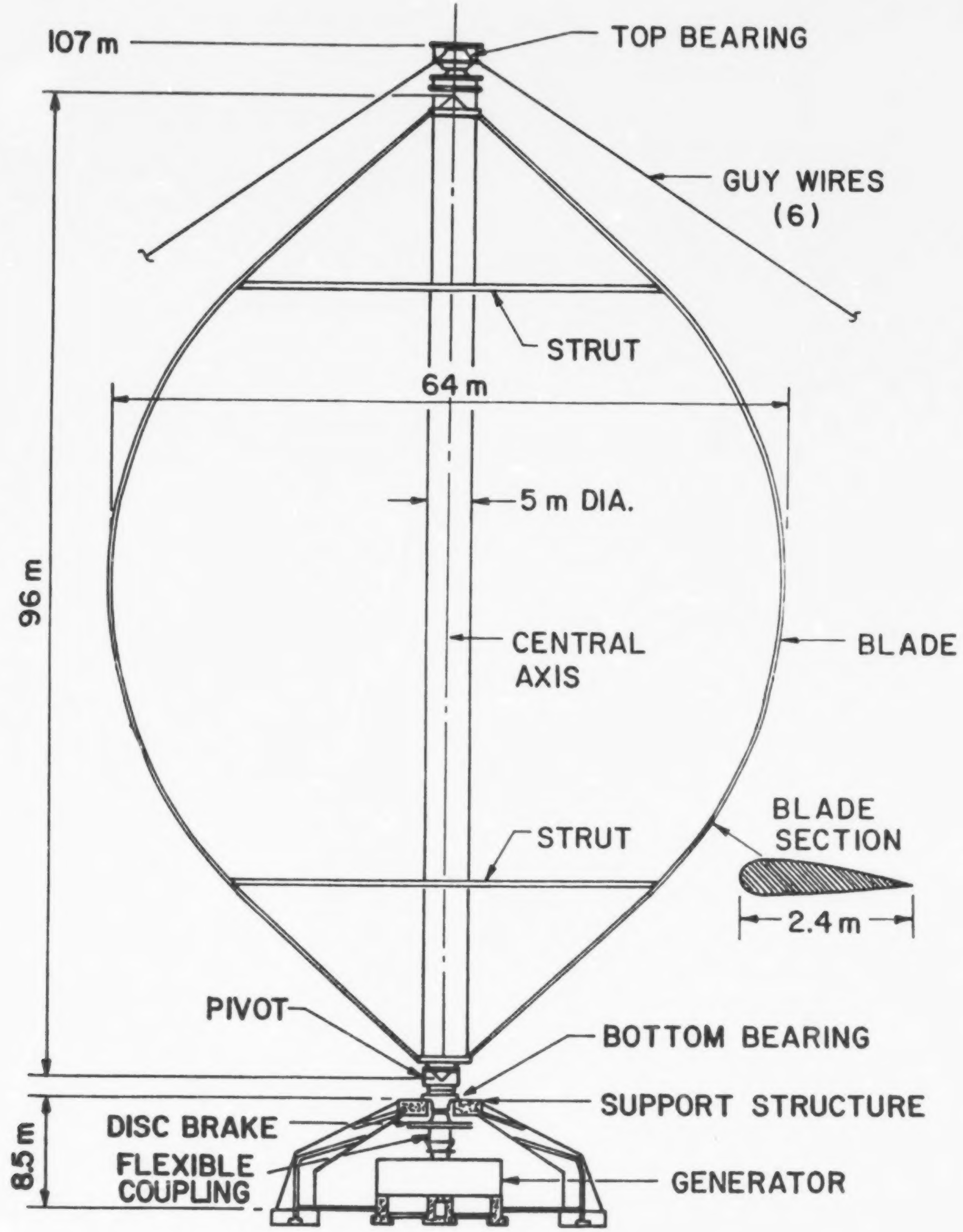
EOLE SITE



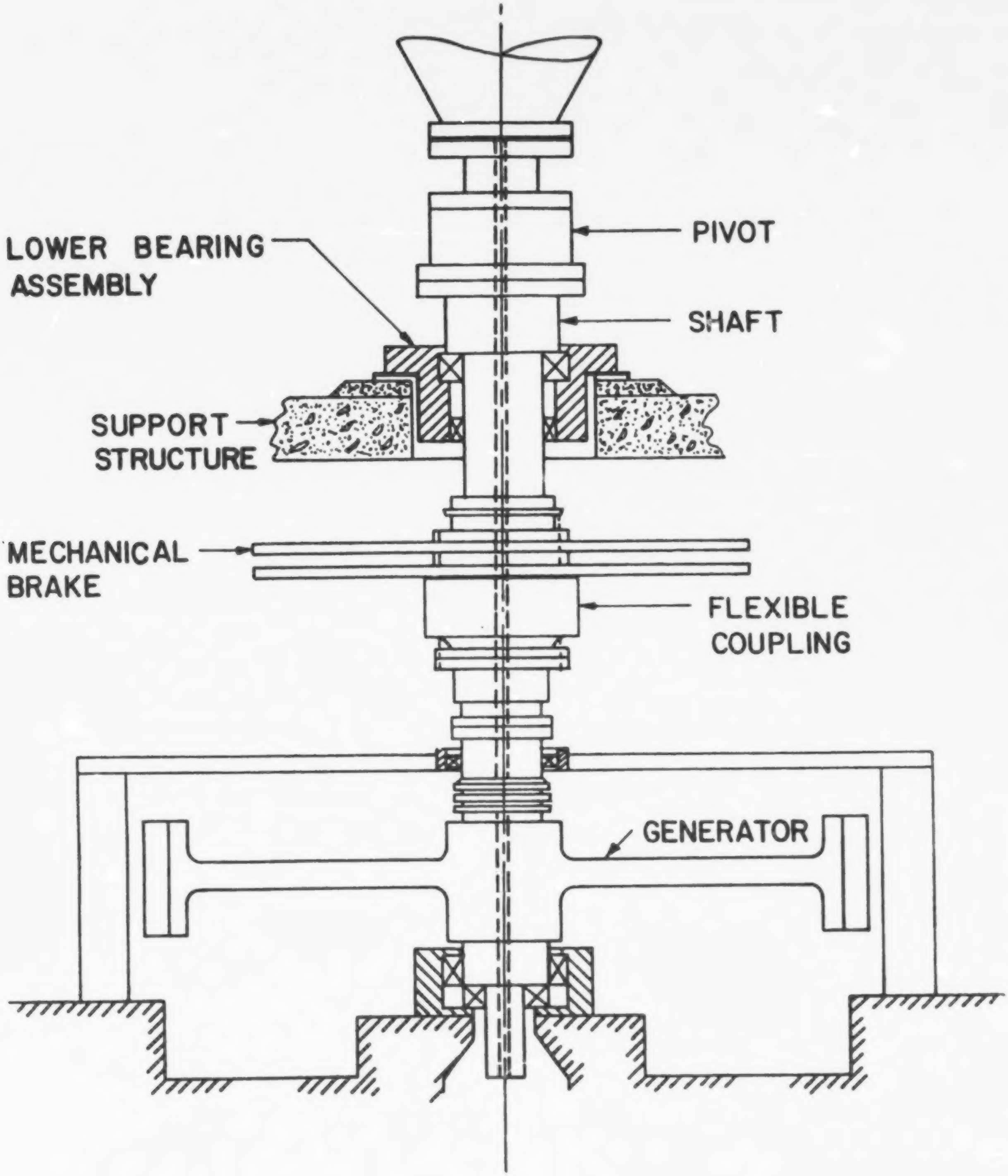
General Layout (Plan)


AXE DU ROTOR
1600
3290
35°
96000
ÉL. 119,00
9000
ÉL. 166.650
MÂT ANTI-RÉSONANCE
VARIABLE
ÉL. VAR
VOIR DESSIN Nº 4200-00271-001-01
VARIABLE
90000

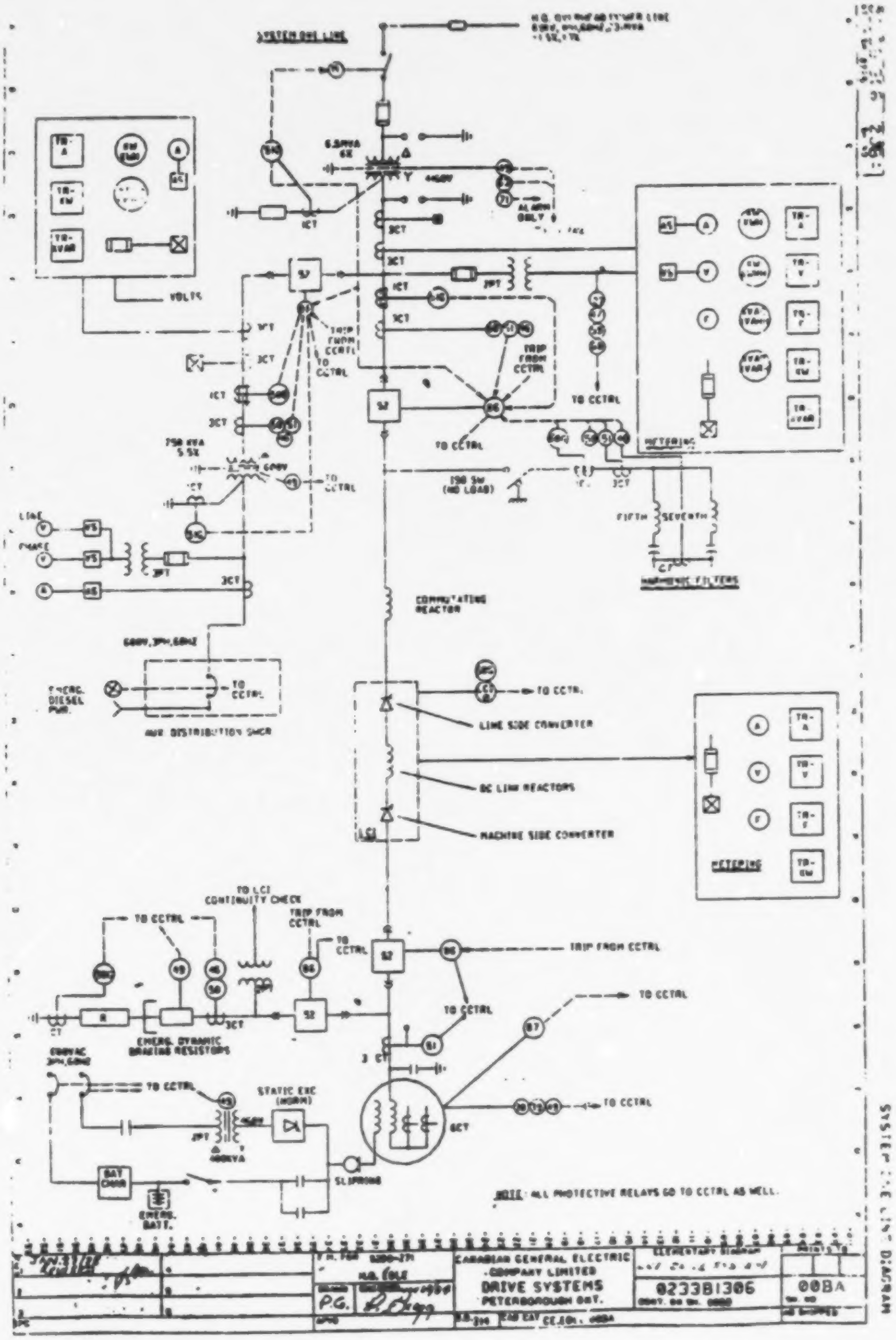
General Layout (Elevation)


107 m
TOP BEARING
GUY WIRES
(6)
STRUT
64 m
5 m DIA.
96 m
CENTRAL
AXIS
BLADE
BLADE
SECTION
STRUT
2.4 m
PIVOT
BOTTOM BEARING
SUPPORT STRUCTURE
DISC BRAKE
8.5 m
FLEXIBLE
COUPLING
GENERATOR

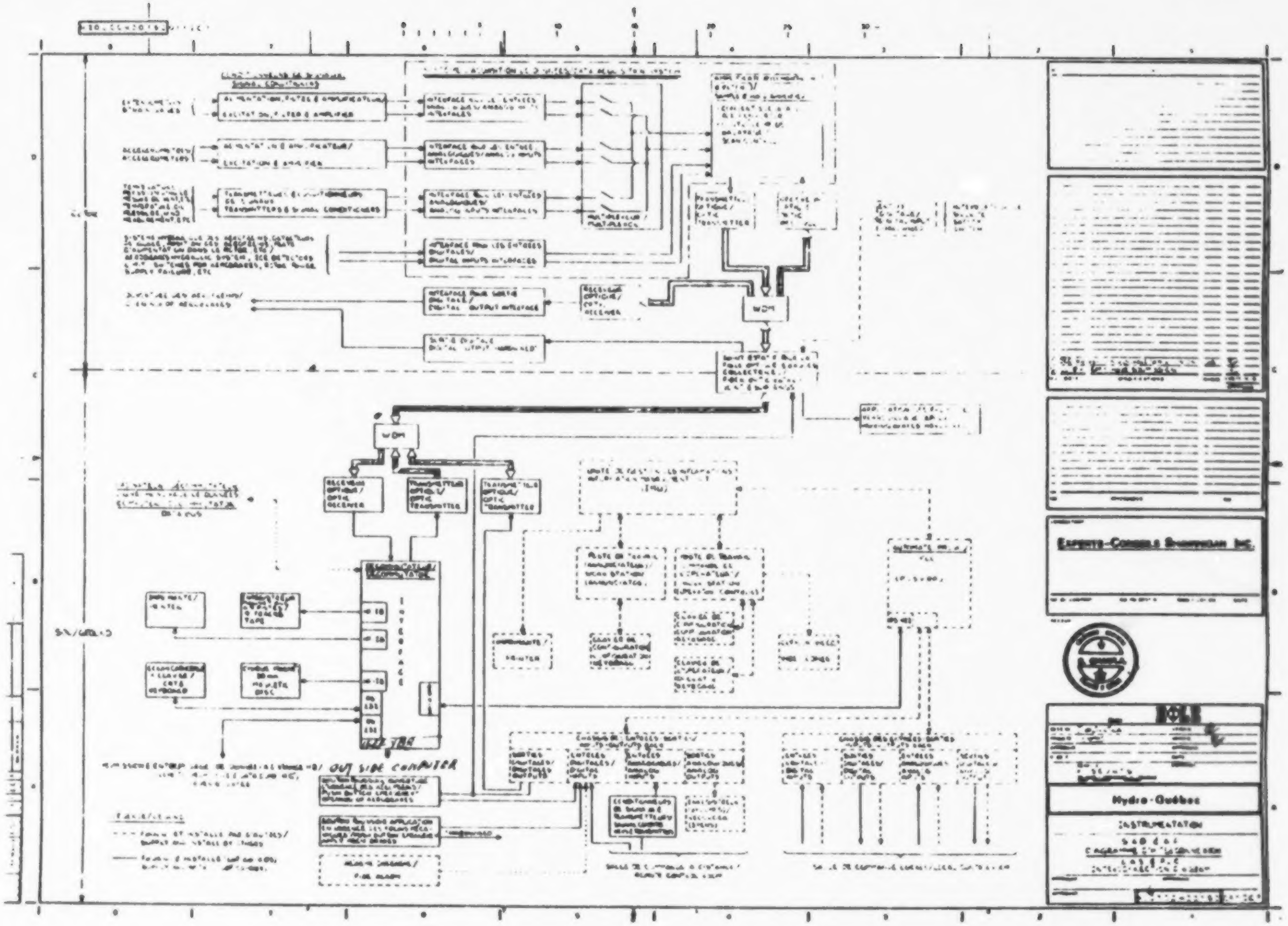
GENERAL CONFIGURATION
OF EOLE VAWTG


PIVOT
LOWER BEARING ASSEMBLY
SHAFT
SUPPORT STRUCTURE
MECHANICAL BRAKE
FLEXIBLE COUPLING
GENERATOR

POWER TRAIN ARRANGEMENT OF EOLE VAWTG

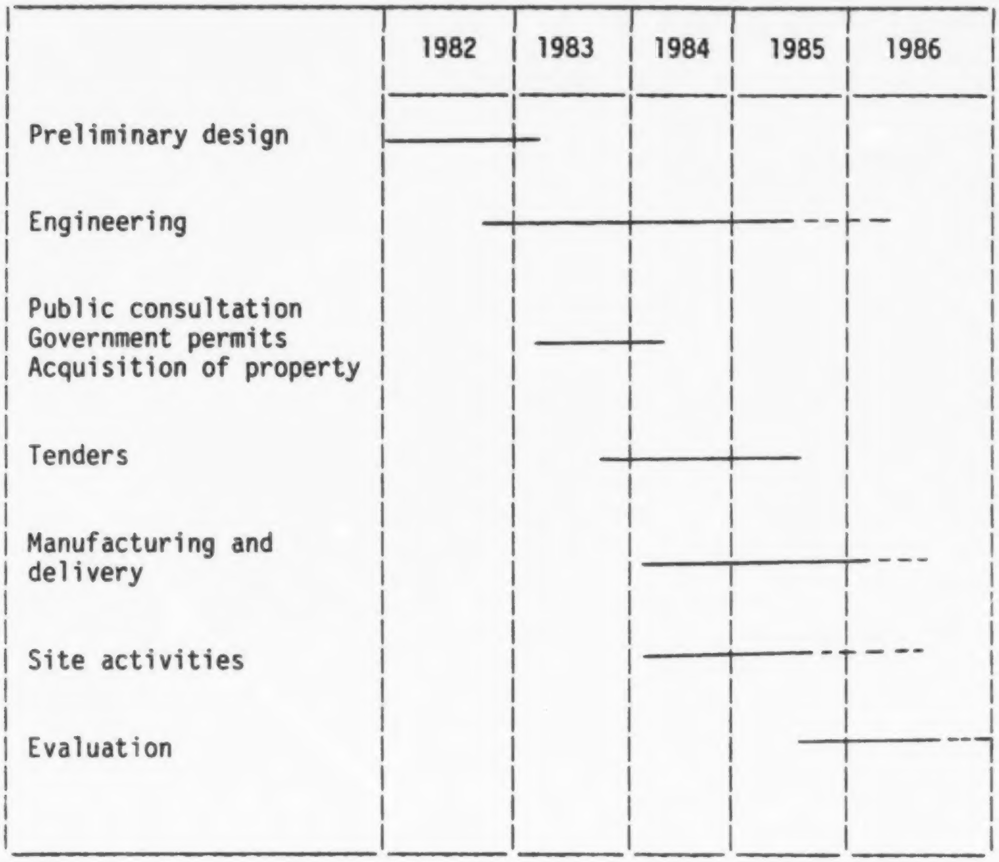

SYSTEM ONE LINE
6.5MVA
6X
4160V
ICT
3CT
2PT
VOLTS
TRIP FROM CCTRL
TO CCTRL
ALARM ONLY
750 KVA
5.5X
600V
LINE
PHASE
680V,3PH,60HZ
EMERG. DIESEL PWR.
AUX DISTRIBUTION SWGR
FIFTH
SEVENTH
HARMONIC FILTERS
750 SW (NO LOAD)
METERING
TR-A
TR-V
TR-F
TR-KW
TR-KVAR
COMMUTATING REACTOR
LINE SIDE CONVERTER
DC LINK REACTORS
MACHINE SIDE CONVERTER
LCI
TO LCI CONTINUITY CHECK
TRIP FROM CCTRL
EMERG. DYNAMIC BRAKING RESISTORS
STATIC EXC (NORM)
SLIPRING
6CT
BAT CHGR
EMERG. BATT.
NOTE: ALL PROTECTIVE RELAYS GO TO CCTRL AS WELL.
CANADIAN GENERAL ELECTRIC COMPANY LIMITED
DRIVE SYSTEMS
PETERBOROUGH ONT.
ELEMENTARY DIAGRAM
0233B1306
00BA
P.G.
SYSTEM ONE LINE DIAGRAM

Electric - Line diagram


WDM
WDM
OUT SIDE COMPUTER
IMPRIMANTE / PRINTER
EXPERTS-CONSEILS SHAWINIGAN INC.
Hydro-Québec
INSTRUMENTATION

Data Acquisition System

SCHEDULE


1982
1983
1984
1985
1986
Preliminary design
Engineering
Public consultation
Government permits
Acquisition of property
Tenders
Manufacturing and delivery
Site activities
Evaluation

An Overview of the Activities in 1985 at the test station for Windmills, Risø

Helge Petersen

Abstract and Introduction

The report is information for the 1985-meeting of the Informal International Group of Test Stations for Wind Turbines. The participants of the meeting are familiar with the test Station for windmills, Risø, for which reason the report only briefly describes the status of the work, and refers to contributions by other colleagues from the test station at the meeting.

Contents

1. The General Scope of Work
2. The Staff and the Budget
3. Industry Relations
4. Approval of Wind Turbines
5. Standard Measurement Development
6. New Facilities
7. International Relations.

1. The General Scope of Work.

The general scope of the work carried out by the Test station is summarized on the page overleaf.

Besides the dayly work emphasized on testing of commercial wind turbines, a number of research projects are performed, summarized in the listing.

2. The Staff and the Budget.

The staff and the budgets have been steadily increasing, and to facilitate recognizing the staff members portraits are presented in Fig. 1. The budget has increased as shown in Fig. 2.

3. Industry Relations.

The close cooperation between the manufacturers and the Test Station is one of the reasons for the rapid development and the increase in reliability and performance of the commercial wind turbines, illustrated in Fig. 3. The failure rate has decreased to 1%. the energy output of similar windmills has doubled in a few years.

Figure 4 shows the measured data of typical 55-kW windmills, the energy production per square metre of the swept area, the disc area. The efficiency of the machines is quite empressing, more than was expected when the development of the stall-controlled windmills was initiated.

4. Approval of Wind Turbines.

Concerning this subject reference is made to the contribution by Mr. Peter Hjuler Jensen.

5. Standard Measurements Extentions.

As will be known to you, the testing of windmills at the Test Station i divided in two categories: standard testing and development testing. On the extension of the standard testing programme reference is made to the contribution by Mr. Per Lading.

6. New Facilities.

One of the new facilities is the experimental set-up for research on Wind/Diesel Systems, and this will be described at the meeting by Mr. Helge Aagaard Madsen, whatfore reference is made to his contribution.

Two other new facilities should be mentioned here,

- an extension of the electrical equipment to test wind turbines with up to 500 kW rated generator power, and combined with this a frequency converter enabling to run machines at a wide range of frequencies, illustrated in Figs. 5 and 6.
- an experimental set-up for vibrational testing of blades for windmills, the life-time test, illustrated in Figs. 7 to 10.

Further new facilities being established for operation next year, and for this reason only listed here, are,

- an experimental windmill or research work,
- a test facility for water pumping windmills, windpumps.

7. International Relations.

The most important of the international relations is of course the cooperation of the test stations. One way of cooperation is the participation in the annual meetings of which this is the 5th, an other is the cooperation on study projects which we have in common.

The Test Station is active in the work going on within the FAO-Networks for application or conservation of energy for agriculture and in rural areas, for which the author is the coordinator for wind energy applications.

Besides this the Test Station has bilateral arrangements with some countries for cooperation, and also, concerning the Wind-/Diesel research, within the IEA-framework.

The Test Station for Windmills was established in 1978, financed by the Danish Ministry of Energy, with the aim of supporting the development of windmills in Denmark.

The Test Station has seven platforms for testing grid connected windmills of generator size up to 500 kW, one for wind/diesel and some for wind pumps.

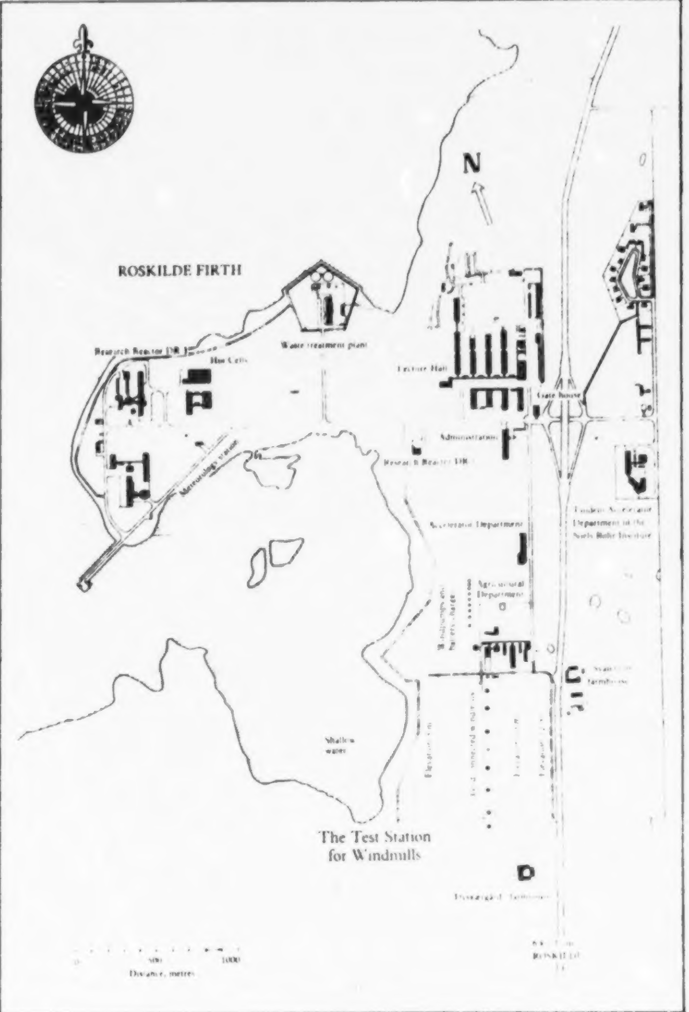
The work programme for the Test Station covers the following areas:

- Standard testing and systems evaluation for licensing windmills in Denmark
- Development testing of windmills
- Engineering reviews
- Consultancy to industry
- Consultancy to authorities. Wind resources assessments
- Research and development

Examples of R&D are:

- Rotor blade aerodynamics
- Dynamic loads in the structure
- Fatigue life analysis
- Blade vibrational lifetime testing
- Airbrake design
- Development of measuring methods
- Safety strategy
- Development of licensing criteria
- Wind/Diesel systems
- Water pumping windmills
- Windmill economics

Testing and engineering reviews are also offered to foreign customers.


N
ROSKILDE FIRTH
Water treatment plant
Hot Cells
Lecture Hall
Gate house
Administration
Meteorology station
Accelerator Department
Tandem Accelerator Department in the Niels Bohr Institute
Agricultural Department
Shallow water
The Test Station for Windmills
0
500
1000
Distance, metres
ROSKILDE

Map of RISØ NATIONAL LABORATORY

The Test Station for Windmills has a staff of 20 and is part of the Risø Department of Meteorology and Wind Energy. Other groups in the Department perform wind resource assessments, development of lifetime computation, measurements on large windmills and management of wind energy projects in developing countries. Other departments at Risø are also engaged in wind energy work:

The Department of Metallurgy, Electronics, Engineering Design and Energy System Analysis. A total of approximately 35 people are engaged in the wind energy work at Risø.

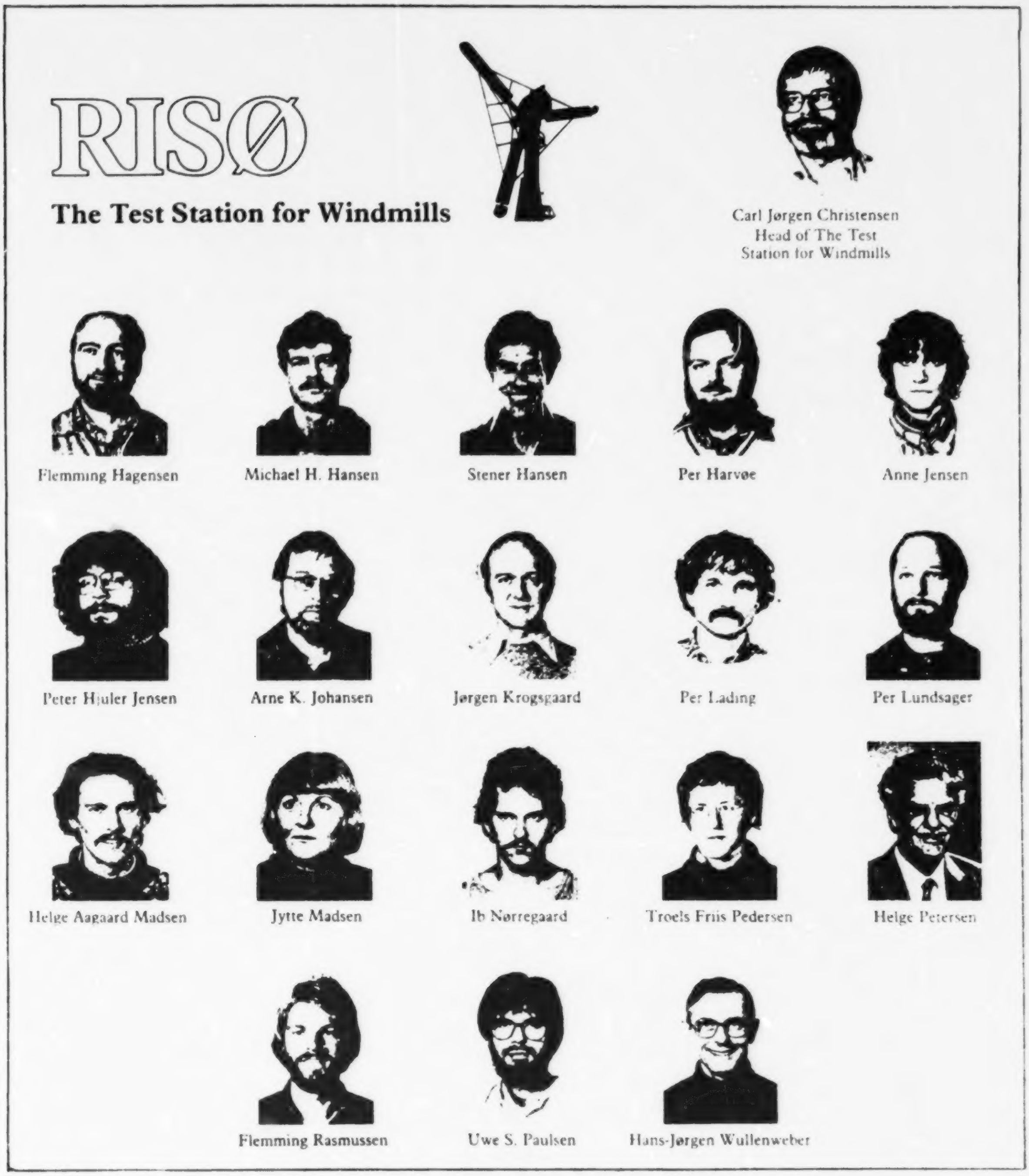

RISØ
The Test Station for Windmills
Carl Jørgen Christensen
Head of The Test
Station for Windmills
Flemming Hagensen
Michael H. Hansen
Stener Hansen
Per Harvøe
Anne Jensen
Peter Hjuler Jensen
Arne K. Johansen
Jørgen Krogsgaard
Per Lading
Per Lundsager
Helge Aagaard Madsen
Jytte Madsen
Ib Nørregaard
Troels Friis Pedersen
Helge Petersen
Flemming Rasmussen
Uwe S. Paulsen
Hans-Jørgen Wullenweber

Figure 1

The staff of the Test Station for Windmills, Risø

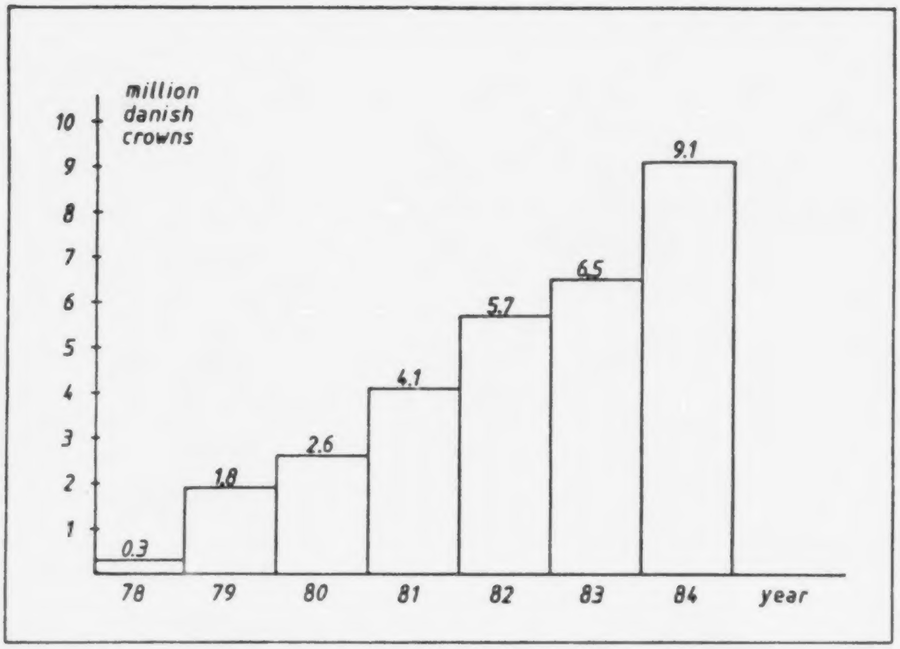
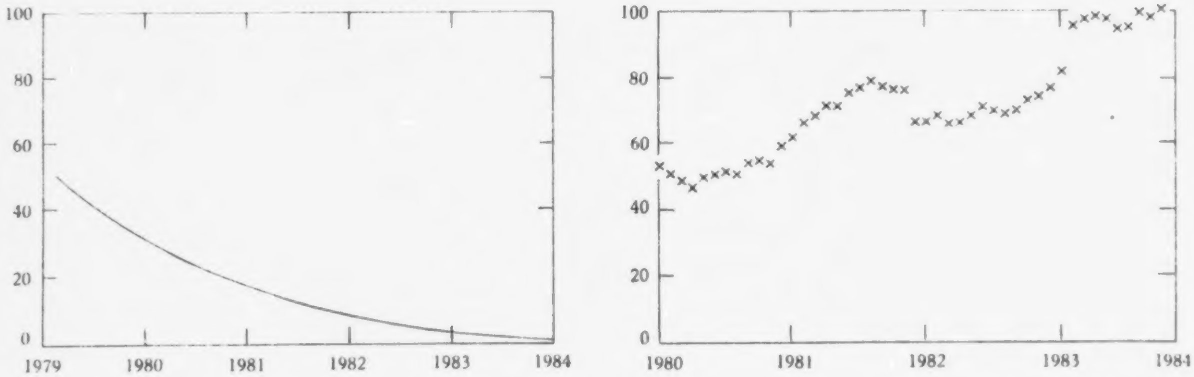


Figure 2

The increase of the budget through the years



Record of 55-kW windmills, yearly probability occurence of major failures in per cent of the number of windmills.

Yearly average production of energy from 55-kW windmills in Denmark, MWh.

Figure 3

Improvements gained in reliability and energy production

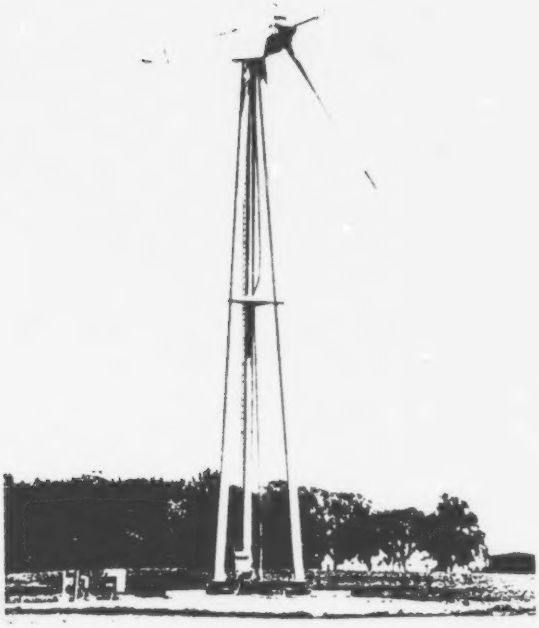


Figure 5

The largest windmill hitherto tested at the Test Station, the 20-m BONUS. 30-m diameter windmills can forwards be tested.

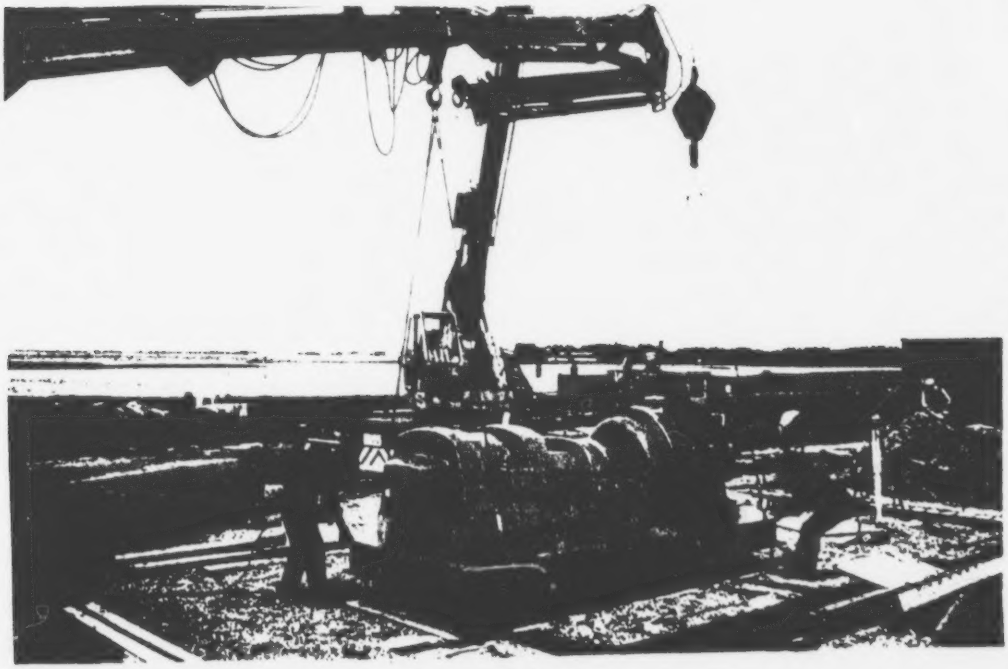


Figure 6

The machinery of the frequency converter

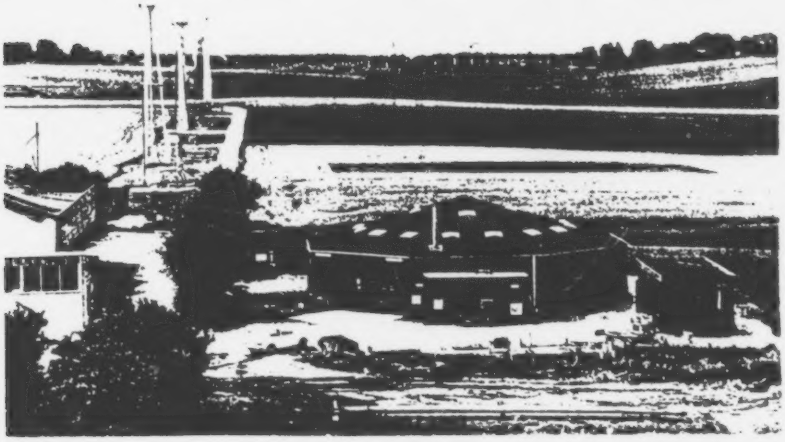


Figure 7

The workshop of the Test Station for Windmills

Figure 8

The test set-up for vibrational testing of blades

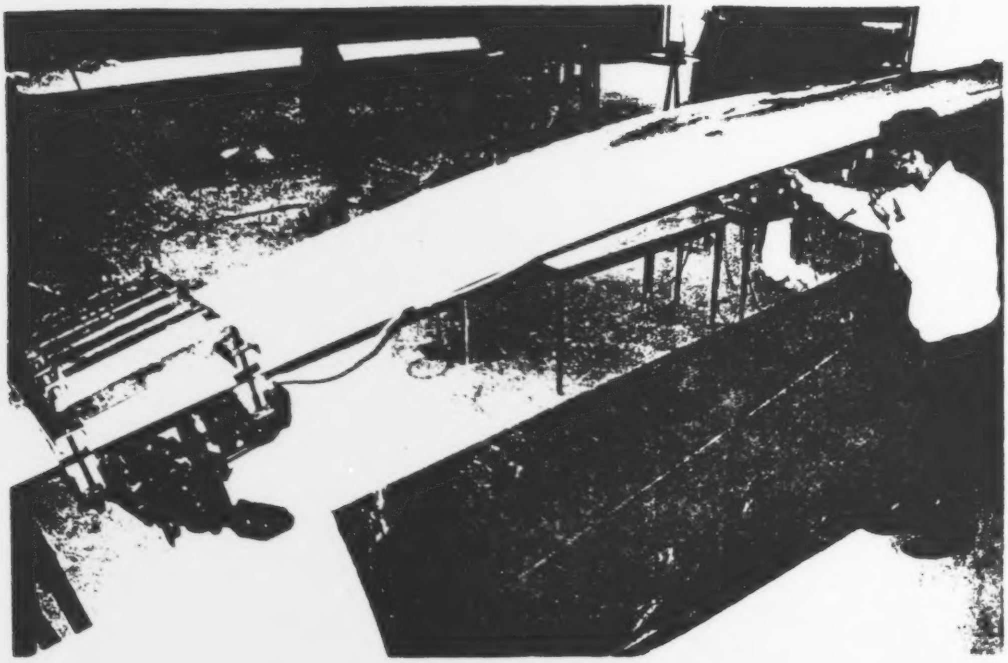


Figure 9

During the life-time test the gradual deterioration is observed stethoscopic

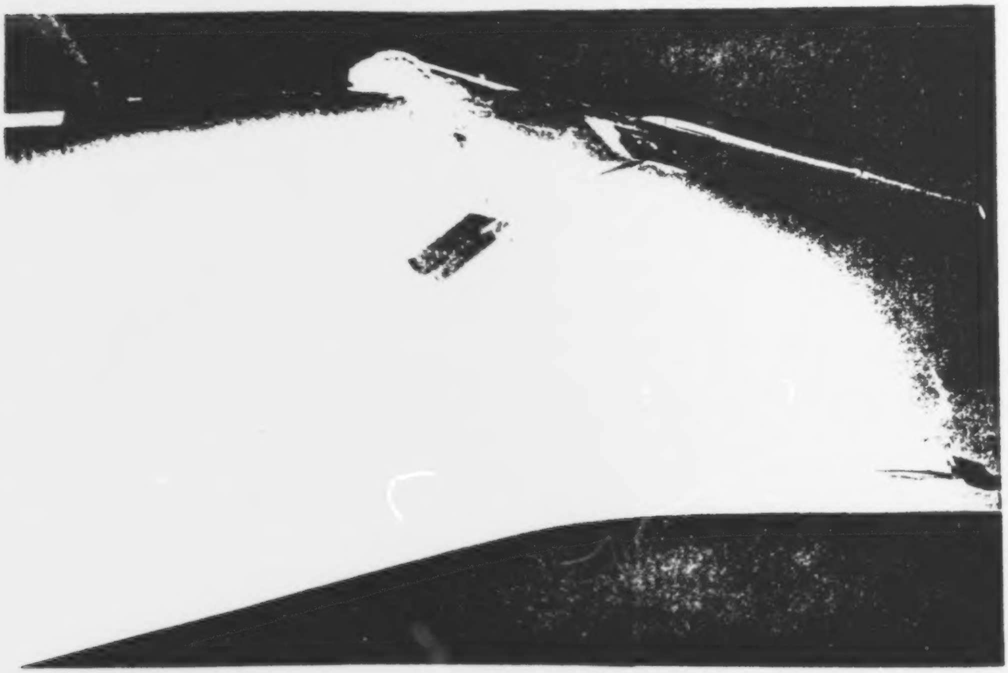


Figure 10

Final failure of a blade in the life-time test

Approval of Wind Turbines
Status 1985

Peter Hjuler Jensen

Contents

1. Introduction
2. Brief History
3. Fundamental Requirements
4. Requirements for the January 1981 act
5. Conclusions
6. References

1. Introduction

In principle a windmill licence issued by the Test Station for windmills, Risø National Laboratory is only an acceptance of the windmill type for government subsidy according to law no 2 of January, 1981 amended in law no. 309 of June, 1982

A license by the Test Station for Windmills is not yet a type certificate, but work is done to reach that aim.

The license is normally accepted e.g. as a documentation for building authorities (safety approval) and as an acceptance by the insurance companies.

In about half a year it is expected that the Test Station license will be accepted as a more general safety license.

The rules for the systems approval of windmills is now "Rules for system approval of windmills in Denmark". (Ref. 1).

2. Brief history

The first government act for subsidising windmills appeared June 1979. Recording to this act, the danish windmill buyer would get a reimbursement from the state of 30% of total costs including installation and connection tc the grid. As a part of the act it was determined that a licensing procedure should be established in order to ensure that only windmill types of a certain standard were to be subsidized. The Test Station for Windmills was appointed as licensing authority for commercially available windmills.

Each windmill type was evaluated individually, and only rather few general criteria were implemented in the beginning. More rigorous criteria were unavailable at the time and work was needed for the development of such criteria. Secondly, for developing windmills it was considered beneficial that the licensing procedure be not too restrictive at first.

When the act expired in January 1981 some 40 types had been licensed and 9.1 mill Dkr. ($ mill 1.1) had been given in subsidy to approx. 300 windmills.
The second act for windmill subsidy after the same system went into effect in January 1981. The subsidy was 20% of total cost, and grants were given to the Test Station to execute and improve the evaluation procedure that forms the basis for a license. Since then the subsidy has varied between 20% and 30%.

The evaluation procedures are currently being extended and reinforced on the basis of the experience gained from licenses already issued. In June 1985 some 1100 windmills ranging from 10 to 350 kW rated power were operating, and some 260 machines were ordered from the approximately 20 danish manufacturers.

3. Fundamental requirements

Table 1 shows the fundamental requirements for stallregulated windmills as implemented in connection with the June 1979 act. At that time it was common to use only one mechanical brake, and a number of serious breakdowns were caused by the inability of these brakes to stop the machines. A runaway fixed-pitch machine increases the rotor power very drastically in the very few seconds needed to keep the rotor rpm sufficiently low for the mechanical brake to be able to stop the operating. Aerodynamic devices that convert the wind to mechanical energy at the point of generation (i.e. the turnable blade tips) proved effective.

The rules specified by the utilities ensure that the grid receives power of satisfactory quality. This leads to the criteria for automatic shutdowns in Table 1.

4. Requirements for the January 1981 act

The requirements, divided into general and specific areas, are primarily made for gridconnected propeller type windmills with induction generators, but they also apply for Darrieus and gyro wind turbines.

The general requirements are connected to the definition of the operating modes of a windmill given in Table 1. It is required that it should always be possible to bring a windmill into a parked condition. In the production mode the security system shall be present so that conditions the may lead to vindmill damage are detected. If such conditions are detected the mill enters an emergency mode and must be shut down or restricted in operation in such a way that damage is avoided. The general requirements tell of the needs, but not how to fulfil them. The specific requirements listed in Table 2 describe how to obtain the required results.

Power regulation by means of any of the methods in Table 3 and any combination hereof is allowed, but yawing out of the wind is forbidden because of the large oscillating forces created in the blades in screw wind. In the start were problems in obtaining effective power regulation by both fixed- and variable-pitch machines, but these problems are today solved with a combination of measurements and calculations.

The grid connection and cut in are strongly influenced by the electric governor. The first of these devices were rather crude producing high cut-in transients. New requirements are now defined by Accounting Department of the union of Danish Power Companies.(Ref 2)

The security system must be of the so-called fail-safe type, i.e. the system actively disengages the braking system, and each element is series connected to the other in a loop. thus each system therefore can engage the brake passively by breaking the loop. Generator overload may be detected by: 1. measuring electric power. 2. measuring electric current, or 3.

measuring generator temperature. Vibrations may be detected by: (a) accelerometer-type transducers and (b) drop-weight actuators. Overspeed must be registered in two independent ways i.e.: (i) by a sensor on the rotor main shaft for activation of the mechanical brake and (ii) by centrifugal forces on the rotor for activation of the aerodynamical brakes.

If one of those elements in the safety system stops the operation, the machine must not start again automatically. The cause of shutdown should be corrected and the windmill restarted manually.

Both braking systems must be able to keep loads on the windmill within design limits, but only the mechanical brake must be able to stop the machine. The aerodynamical brake shall keep the rotor rpm at values so low that the rotor power is within capability of the mechanical brake. This should be able to stop the windmill without help from the aerodynamic brakes.

It is required that the Test Centre staff inspect the windmill type in the workshop and in operation. As part of the workshop inspection a static load test of one rotor blade must be performed under supervision of the Test Centre staff. It is a current requirement, that under a triangular load test corresponding to 300 N/m^2 swept rotor area the blade must not experience any damage.

Finally it is required, that there must exist a measured power curve on a rotor similar with the actual windmill.

5. Conclusion

The licensing procedure coupled to a policy of subsidy has played a significant role in the development of windmills in Denmark.This licensing procedure has emerged from a liberally administered set of a modest number of general rules to a stage where more detailed requirements are more rigorously administered, and the development of actual design specifications is today one of the main parts of the work on the Test Station.

TABLES

brakes	Mechanical brake able to stop the machine under full load. Parking brake system. Aerodynamical braking system (blade pitching, spoilers, tip brakes). Activated automatically by centrifugal forces during overspeed. Must keep rotational speed within safe limits at any windspeed.
grid connection	Further utility requirements see Ref 2.
electric governor	Cut-off criteria: Frequency: More than 1 Hz deviation Voltage: More than 10% of nominal voltage Phases: Loss of phase symmetry.
disconnection	Manual circuit-breaker must be available.
reconnection	Manual restart following one of above mentioned cut-off reasons except grid faults.

Table 1. Fundamental requirements (June 1979 act)

Parking	Disconnected from the grid. rotating system must be locked (except when operated manually)
Production	Connected to the grid. Produced power according to wind speed. Power production must be within rated power. Security system must be able to function.
Emergency	Security system detects abnormal condition. Windmill is shut down. Security system prevents overload.

Table 2. The three operational modes of a windmill and general requirements.

Power regulations	By stall, blade pitch or spoilers
Grid connection	Limited cut-in transients
Security system	Each element in SS actuates brakes registration of - Drop of supply voltage - Generator overload - Nacelle vibrations - Overspeed (Different activation of mech. and aerodynamic brakes) - Power cable twist - Voltage deviations - Frequency deviations - Dropout of 1, 2, or 3 phases
Braking systems	Mechanical brake Aerodynamic brake
Tower/foundation	Calculation by professional engineer on basis on specified static load.
Rotor/blades	Proof load tests supervised by the Test Station.

Table 3. Specific requirements

References

Ref 1: "Rules for system approval of windmills in Denmark" August 1984, The Test Station for Windmills.

Ref 2: "Nettilslutning af mindre vindmøller", Komitérapport nr. 66, 1985-02-25, DEFU.

THE WIND/DIESEL DEVELOPMENT PROGRAM AT RISØ NATIONAL LABORATORY STATUS 1985

Helge Aagaard Madsen

Contents.

1. Introduction.
2. The Risø W/D Programme.
3. Two W/D Systems (Risø et al.).
4. W/D test facility and testing.
   4.1 The W/D test facility.
   4.2 Standard W/D test procedure.
References.

1. Introduction.

The wind/diesel program at The Test Station for Windmills, Risø National Laboratory, was initiated in 1982 and during 1984-1985 most of the experimental equipment has been installed. Different subjects within the program have previously been published (ref. 1-3) and the present paper aimes at reviewing some of the work carried out until now.

As almost all consumers of electricity in Denmark are connected to the main national grid the danish market for w/d systems is limited. In spite of that, danish manufacturers of wind turbines, diesel generator sets, power electronics, control systems etc. have shown a strong interest in the w/d programme at Risø. The same holds for many of the visitors at Risø. The interest can be explained by the big markets for w/d systems in remote areas, both within industrial countries as well as in development countries.

Because of the above mentioned interest from danish industry the Risø w/d programme is carried out in a close collaboration with several manufacturers who have contributed different parts of equipment to the experiments. Major funding is contributed from the danish ministry of Energy and the Nordic Council of Ministers, who support a part of the w/d programme that is carried out in co-operation with Chalmers University of Technology, Göteborg, Sweden.

2. The Risø W/D Programme.

The different activities of the Risø w/d programme that have been carried out or are presently going on or are planned can be summarized as follows.

a. Development of two w/d systems.
    a1: 30 kW state-of-the-art system without energy storage. (In corporation with Danregn Vindkraft A/S, DK, and Bukh Diesel A/S, DK.)
    a2: 25 kW advanced system with energy storage. (In coorporation with Chalmers University of Technology (CTH), Göteborg, Sweden.)

b. Test facility and the testing of w/d systems.
    b1: Establishment of a universal test facility for w/d systems.
    b2: Testing the two w/d systems mentioned above under a1 and a2.
    b3: Development of a standard procedure for testing w/d systems.

c. Measurements on a small grid.
    c1: Measurements of consumed active and reactive power on the grid of the island Anholt.

d. Research and development.
  - d1: Diesel start/stop (start with flywheel).
  - d2: System dynamics (short time simulation).
  - d3: Control strategies.
  - d4: System economics (long time simulation).

e. Consultancy to industry.

Below, some of the activities listed will be discussed in more details.

3. Two W/D systems (Risø et al.).

3.1 30 kW state-of-the-art system.

The 30 kW state-of-art system, fig. 1 and fig. 2, can be characterized as a simple system and it has no energy storage. Some main data for the system are:

Wind turbine

- 55/11 kW stall regulated turbine with two asynchronous alternators.
- 38 and 54 rpm rotor speed.
- Microprocessor based control system.

Diesel generator set

- Super-charged diesel, 30 kW at 3000 rpm.
- 60 kVA, 2 poled synchronous alternator with a compound voltage regulator.
- Diesel and alternator connected via an electromagnetic clutch and a shaft with a flywheel.

Dump load

- A 75 kW resistor dump load which through thyristors can be regulated in steps of 600 W.
- Alternatively, also a resistor dump load with a phase angle regulation will be tested.

Control system

- An analogue system to control the diesel start/stop, the coupling/uncoupling of the synchronous alternator from the diesel, and the dump load.

The system has been designed to run in either of the three normal w/d modes, 1) d.g.s. alone, 2) wind turbine alone, and 3) d.g.s. and wind turbine in parallel. Running in mode 2 the flywheel and the electromagnetic clutch allows a rapid start of the diesel in case of a sudden deficit in wind speed or increase in power demand.

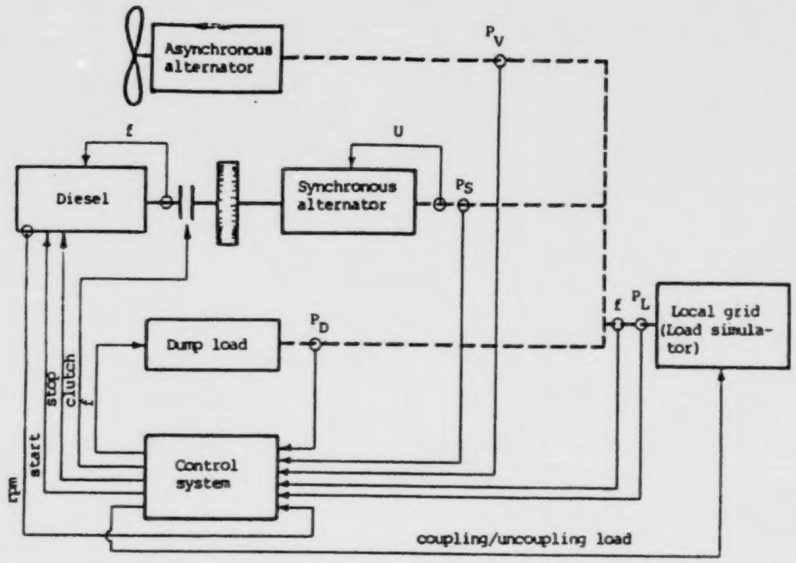

Asynchronous alternator
P_V
f
U
Diesel
Synchronous alternator
P_S
Dump load
P_D
f
P_L
Local grid (Load simulator)
rpm
start
stop
clutch
f
Control system
coupling/uncoupling load

Fig. 1 The 30 kW state-of-the-art W/D system without energy storage, developed by Risø.

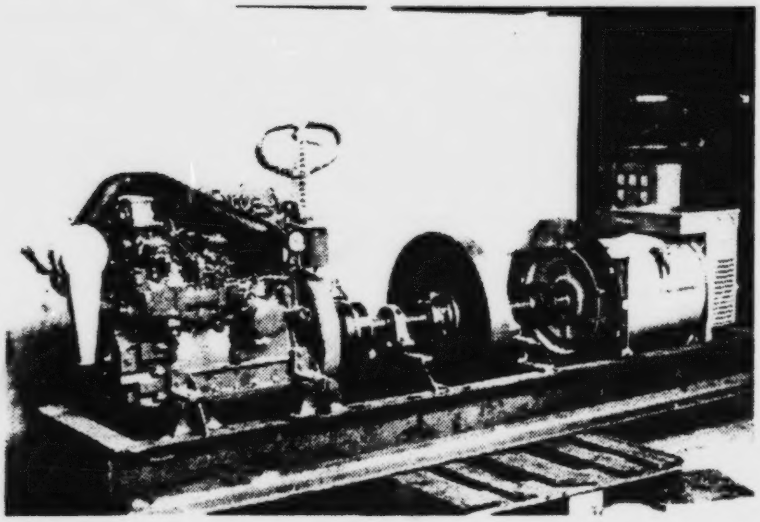


Fig. 2 The 30 kW state-of-the-art system before installation.

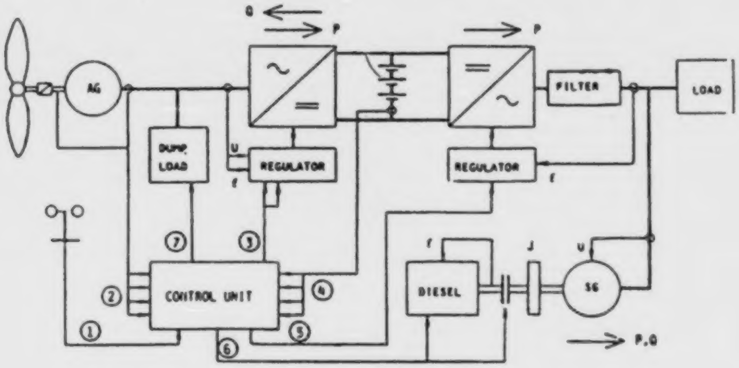
In the design of the control system, importance has been attached to the flexibility of the system as concerns adjustment of the control signals to the dump load and to start/stop of the diesel. Further, importance has also been attached to maintaining the wind turbine as an autonomous unit with its own control system. This means that the turbine can be coupled to the local grid anywhere as no control cables to the overall control system are needed.

The status of the system is that all of the components except the control system has been installed and instrumented and tests with the d.g.s. have started.

3.2 25 kW advanced system.

Through a collaboration project with CTH, Sweden, Risø also participates in development and testing of a 25 kW advanced w/d system with energy storage. The work has been split so that construction and laboratory tests are carried out at CTH, whereas the final field testing will be performed at Risø.

The system lay-out is sketched in fig. 3 and described in more details in ref. 4.



1. Wind speed
2. Input signals for wind power optimation
3. Reference values for wind power optimation
4. Accumulator state
5. Output current limiting
6. Diesel start/stop
7. Power limiting

Fig. 3 The 25 kW advanced W/D system with energy storage, developed and tested in collaboration with Chalmers University of Technology, Sweden.

The same wind turbine as contained in the state-of-the-art system will be used. However, a 22 kW asynchronous alternator will be installed in the turbine and the rotational speed of the rotor lowered so that the maximum power is limited to about 22 kW.

Between the 25 kW converter and inverter a battery storage is connected which can supply power to the grid for about 20 minutes at full load. Both the wind turbine and the d.g.s. can recharge the batteries.

A special feature of the system is that both the frequency and voltage at the wind turbine can be controlled. As an example, a better efficiency of the alternator at partial load can be achieved if the voltage is lowered.

At the present time the system is under construction and full scale laboratory tests are performed at CTH. Probably the field testing of the system at Risø will start at the turn of the year 1985-1986.

4. W/D test facility and testing.

Grid-connected wind turbines have now during several years been tested at Risø. It was therefore natural as a part of the w/d programme to establish a flexible test facility for w/d systems.

The first systems to be tested will be the two systems mentioned above under 4.2 and 4.3. Later on, it is expected that commercial w/d systems will be available and that the industry will need to have a standard test of their w/d systems, in the same way as it is presently being done for grid-connected wind turbines.

4.1 The W/D test facility.

The permanent installations for w/d testing are situated to the north of the row of grid-connected wind turbines of the Test Station for Windmills, fig. 4a and 4b. In the present configuration the upper limit of w/d systems to be tested is 75-100 kW. The main components of the test facility are listed below.

1) A standard foundation able to accommodate all commercially available wind turbines with a base load corresponding to a 20 m diameter rotor on a 24 m tower. Two rotor diameters to the west the meteorological tower is placed.

2) A 20 foot container where the d.g.s. of the w/d system is placed. Different equipment as fuel supply system, engine cooling system and exhaust system is permanently installed in the container and the same holds for different measurement transducers.

3) A computer controlled load simulator which can simulate max. 75 kW in steps of 600 W and 25 kVar in steps of 200 Var.

4) A central power switchboard of a modular design is placed in an office trailer situated close to the container, fig. 6. At the switchboard the different components of the w/d system can either be coupled together and thus form a local grid, or they can be coupled to the main grid. Each module is instrumented to measure current, active and reactive power whereas voltage and frequency are measured centrally in the switchboard. Equipment for remote control of diesel and wind turbine are also placed in the office trailer.

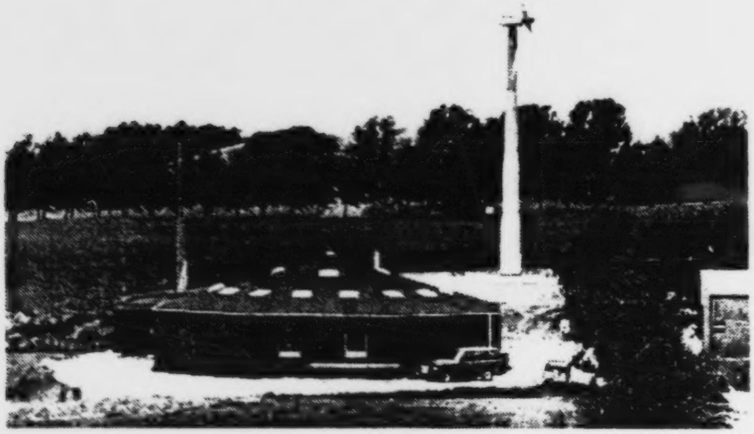


Fig. 4a The W/D test facility is situated to the north of the eight edged workshop. To the left the W/D office trailer is seen dimly.

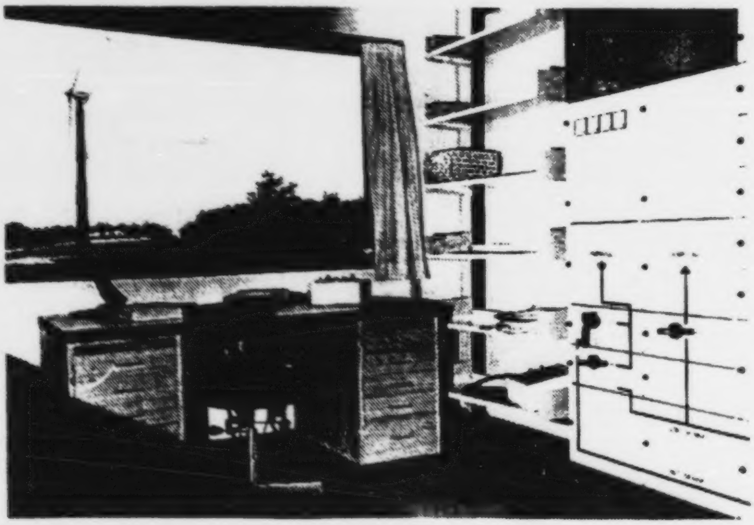


Fig. 4b View from the office trailer to the W/D turbine. To the right the central W/D switchboard is seen.

5) A 40 channels measurement system based on a HP9920S computer with a HP3497A datalogger and with a hard disc.

The w/d test facility is now operational and measurements are performed on the state-of-art system.

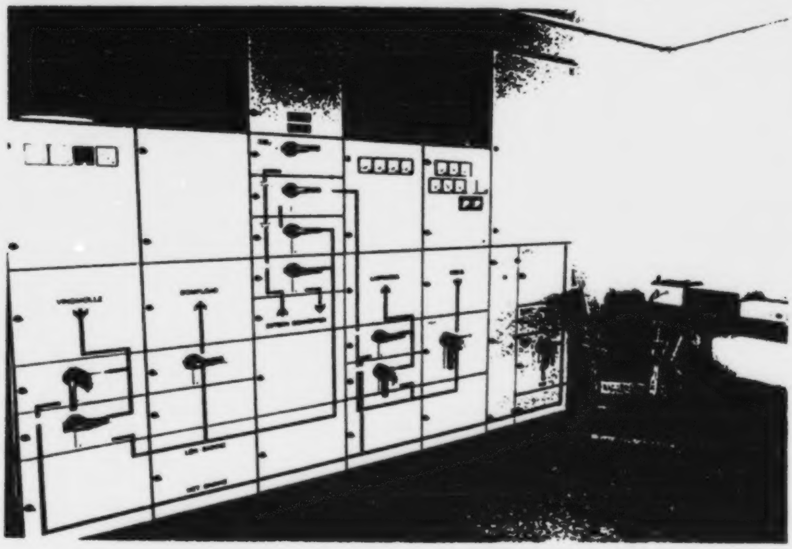


Fig. 5 The W/D switchboard is of a modular construction. The different components of the W/D system can either coupled together to form a local grid or they can be coupled to the main grid.

4.2 Standard W/D test procedure.

The standard tests on grid-connected wind turbines carried out at Risø during several years, ref. 5, seem to have been quite valuable for the wind turbine manufacturers as well as for the purchasers of the machines.

On the basis of a measured power curve at Risø and in combination with the Danish Wind Atlas wind energy prediction method, ref. 6, the annual energy production for a specific turbine on a specific place in Denmark can now be estimated within a diviation as small as +/- 10%. This is the most important piece of information a purchaser wants to know.

Another important question concerns the lifetime and the reliability of the turbine. To answer this question, a considerable number of function tests and measurements of structural loads, vibrations etc. are needed (also contained in the Risø standard test of grid connected turbines). In combination, the data on energy production and lifetime enables the investment in a wind turbine to be fully analyzed.

For a purchaser of a w/d system the same two questions have to be answered although the first question may be put in another way as: What is the savings of fuel per year? A third question concerning power quality is also relevant for w/d systems.

To formulate a w/d test procedure which fulfils these requirements seems to be much more complex compared with the same problem for grid-connected wind turbines.

Especially this is true as concerns the fuel savings predictions and particulary for w/d systems with storage. This is due to the fact that in a w/d system we have as input parameter, besides the wind speed, also the load demand pattern. The latter has a substantial influence on the efficiency of a w/d system and the variations in the load demand seems to be highly site dependent.
The final presentation of the performance of a w/d system for a specific load demand pattern could be a curve showing the relative fuel savings (ratio between actual fuel used and fuel used in diesel stand alone) as function of annual mean wind speed. Further it should be possible to work out the curve for other load patterns.

Such a procedure requires a high degree of interaction between measurements and calculations based on long time simulation models. The Energy Systems Group at Risø is developing a model of that type and similar work is carried out by other institutions, e.g. ref. 7.

The subject standard tests of w/d systems is discussed in more details in ref. 3 where also a first proposal for a standard test procedure is outlined.

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Measurement of Eigenfrequences on Windmills.

Per Lading

Contents.

1. Introduction.
2. Modes.
3. Measurements.
4. The analyze.

1. Introduction.

A part of the standard test programme (1) at the Test Station for Windmills, Risø, is to investigate whether any dangerous vibrations might occur in the structure under operation.

To investigate whether such vibrations occur or not under normal operation might not be so difficult. If you analyze the power fluctuations or the fluctuations of the shaft torque with help of a spectrum analyzer, you will find the dangerous vibrations if they exist.

But it might be a problem to analyze the important modes in the structure and the eigenfrequencies they represents.

This analyze is important not only when dangerous vibrations are observed, because the consequences of a change in the windmills design (using other components, changing the rpm etc.) can easier be foreseen with such a knowledge.
Dangerous vibrations can especially be expected to be found when a eigenfrequency is near p (rotor rpm) or a multiple of this.

The Test Station for Windmills has developed at method for analyzing the important modes. This is now a part of the standard test programme.

The equipment for this analyze is a two channel spectrum analyzer (Hewlett Packard 3582A).

2. Modes.

The example used here is a electricity producing three bladed windmill with rigid hub, fixed pitch and forced yaw, the most common danish windmill design.

Some important modes might be these:

1. Bending of tower.

2. Torsion of tower.

3. Flapwise bending of blades with angular movement of hub (fig. 1).

4. Flapwise bending of blades with no angular movement of hub (fig. 2).

5. Edgewise bending of blades, all blades move in same direction (fig. 3).

6. Edgewise bending of blades, two blades in one direction, one in the opposite direction (fig. 4).

7. Torsion in transmission system (e.g. with a flexible coupling).

These are mentioned as examples. Other important modes of course exist, for instance the properties of the yaw system might give some.

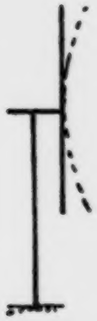

FIG. 1

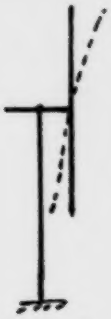

FIG. 2

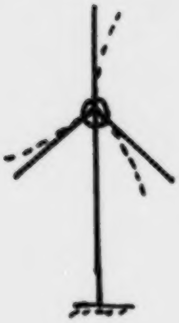

FIG. 3

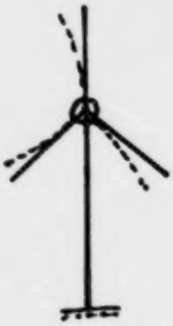

FIG. 4

3. Measurements.

As a standard strain gages are mounted on:

1) The main shaft for measuring torsion.

2) At the root of one of the blades for measuring bending both in flapwise and edgewise directions.

During operation spectra are measured for the power and for the actions of the strain gages.
Examples of such measurements are shown on fig. 5, 6, 7, and 8.

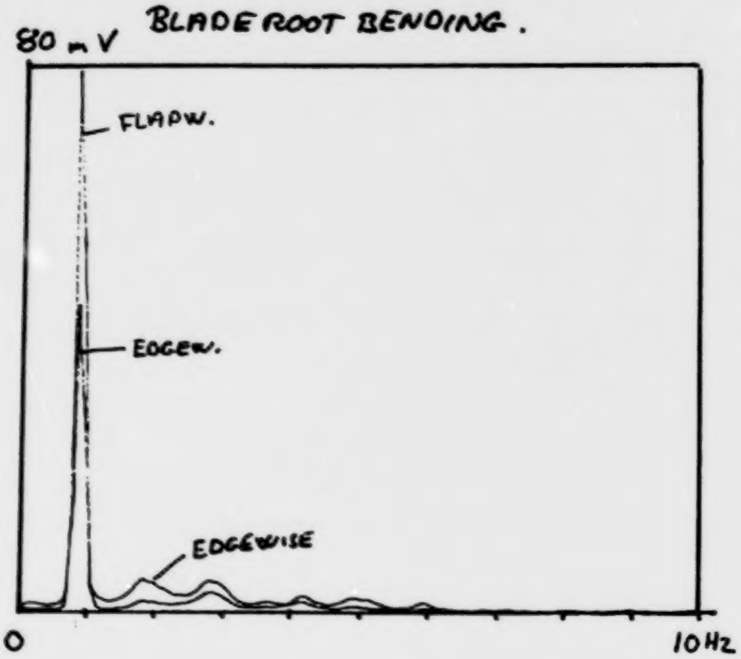

FIG. 5

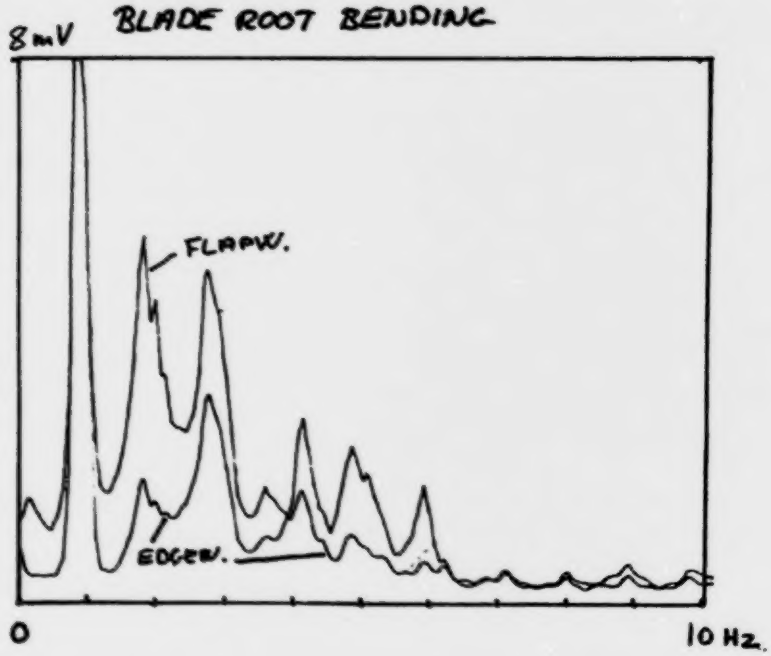

FIG. 6

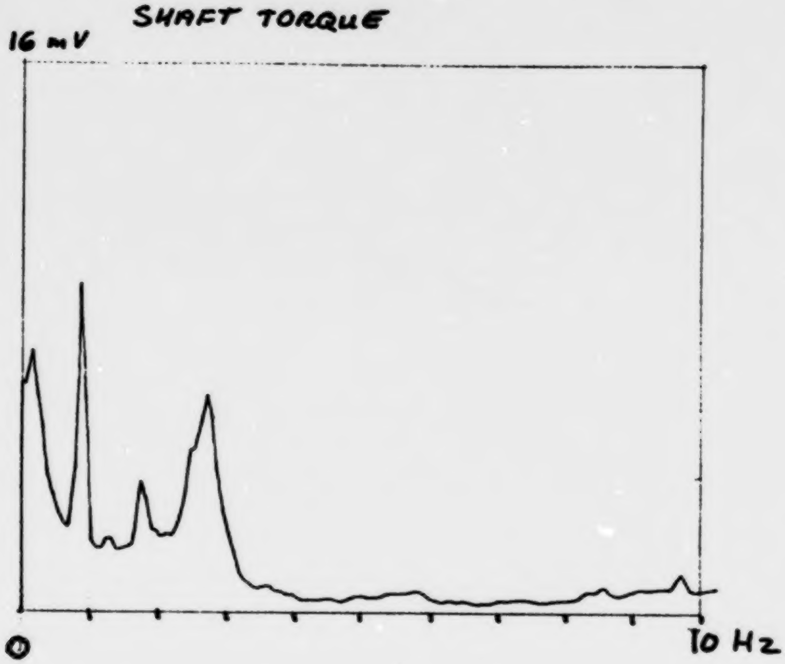

FIG. 7

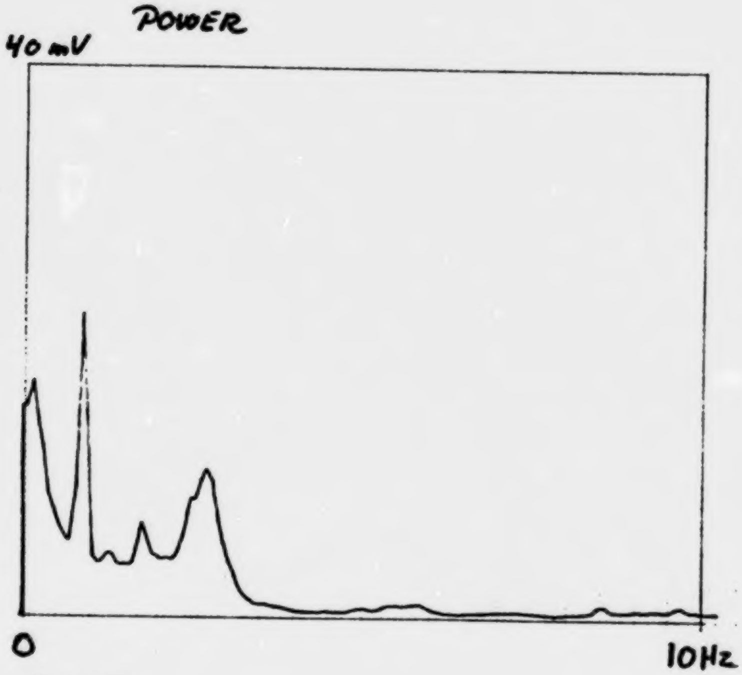

FIG. 8

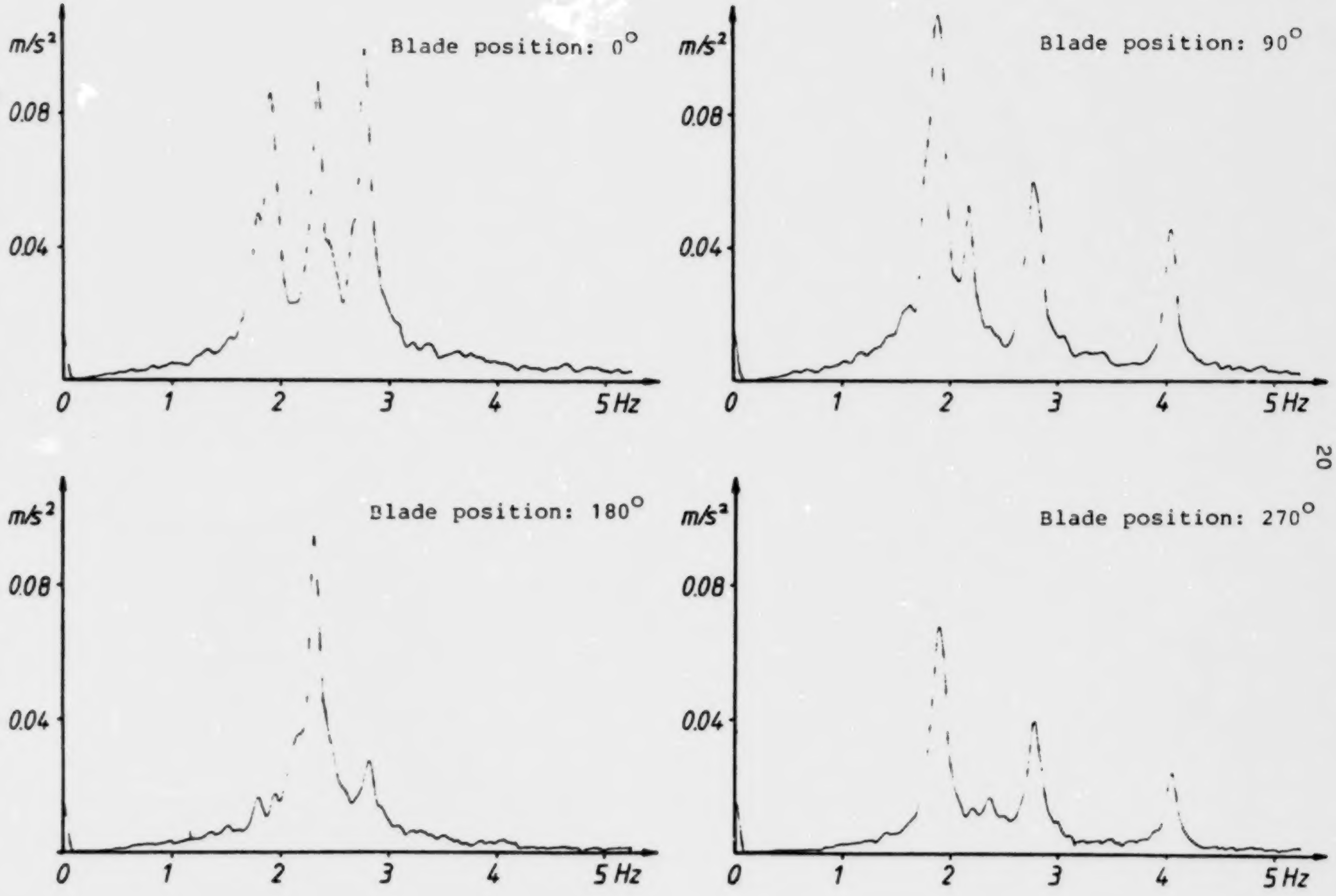

Fig. 9. Frequency spectra for the windmill. (FROM REF. 2)

Due to our experience, the eigenfrequencies can best be found from the strain gages on the blade root. Because of damping more eigenfrequencies might be very weak or disappear at the shaft torque or at the power.

Measurements at the blade root strain gages are also done when the rotor is not rotating.
It is done in four positions of the blade: Vertical up and down position and the two horizontal positions.
Because the brake not must be activated, the measurements must be done at low windspeeds, where the windmill do not start.
An example of such measurements can be seen at fig. 9 (from ref. 2)

4. The analyze.

The measurements described can be very helpful when analyzing the origin of the eigenfrequencies.
The seven modes listed before can be arranged in a diagram in this way:

		NUMBER OF MODE						
BLADE POS.	DIRECTION	1	2	3	4	5	6	7
HORIZONTAL	FLAPW.	+	+	+	+	-	-	-
	EDGEW.	+	-	-	-	+	+	+
VERTICAL	FLAPW.	+	-	+	+	-	-	-
	EDGEW.	+	+	-	-	+	+	+

A "+" indicates that the frequency of the mode is expected to be found, a "-" that it is expected to weak or not to appear.

With the help of such a diagram you can analyze which modes do course which peaks of frequencies from your measurements of the stationary rotor.

Then you can compare these results with the spectra from the rotating rotor. You must have in mind that the frequencies change a little when the rotor is running and that you always will find p (rotor rpm) and 3p in these spectra.

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The Horizontal Axis Research Wind Turbine at Risø National Laboratory.

Jørgen Krogsgaard
The Test Station for Windmills
Risø National Laboratory
Denmark

Contents

1. Introduction.
2. Description of the Research windmill
    2.1 The Nacelle
    2.2 Rotor and Hub
    2.3 The Tower
    2.4 Electrical Equipment
    2.5 Measurement Transducers
3. R&D projects for the Research Windmill
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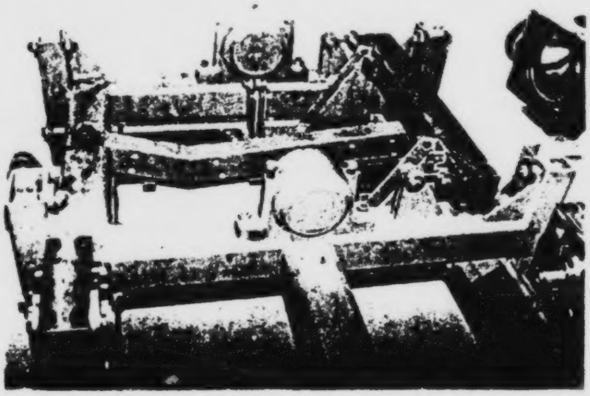
4. Status - August 1985
Acknowledgements.

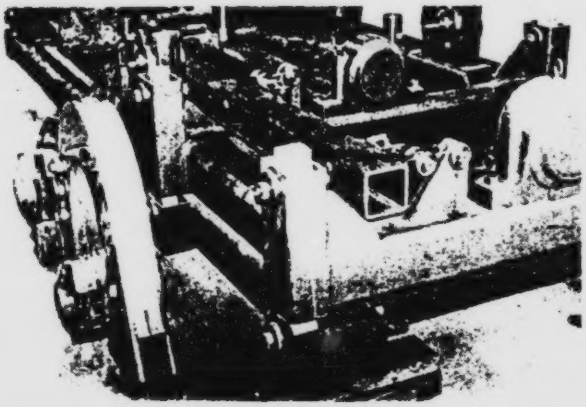
Paper presented at the WindPower 85 Conference, San Fransisco, USA, August 22-25, 1985.

The bearings are made as two hinges that together with an adjustable stay are mounted on a console bolted to the yaw mechanism on the tower top. The hinges are located so that the forces in the stay are small. The windmill is intended to run as an upwind machine but the design allows for downwind operation as well.

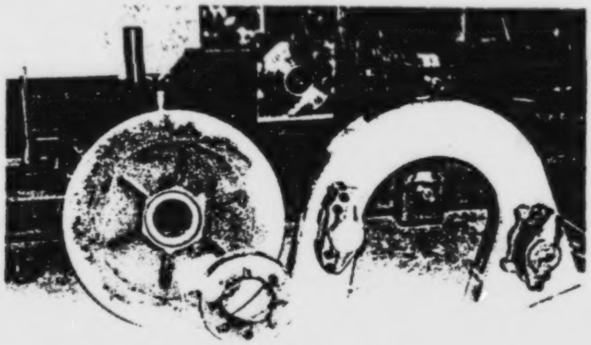


The rotor shaft frame.

At the front end of the main frame a rotor shaft frame is mounted on four vertical support stays, kept in place by three horizontal measurements stays. The rotor shaft is hollow and the hub flange is a forged part of the shaft. It is supported by bearings on the rotor shaft frame and is connected to a hollow-shaft gearbox. The stay taking the reaction force of the gearbox is at the same time a measurement stay. At the rear end of the main frame is a console intended for use in the case of blade pitch control. The rotor shaft has a smooth part intended for strain-gauges, located between the hub and the front end main bearing.

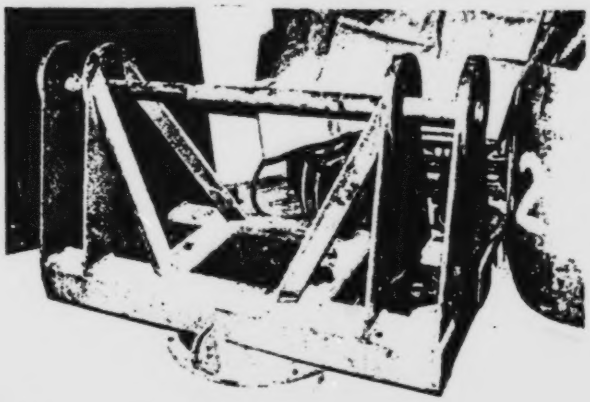


The rotor shaft frame on brake device



The brake device

The brake system consists of a brake disc on the rotor shaft with 2 hydraulic calipers on a separate support. The hydraulic pump etc. is mounted in the opposite end of the main frame. The brake system also incorporates a locking device for use at repair or extended stand-still.



The supporting frame.

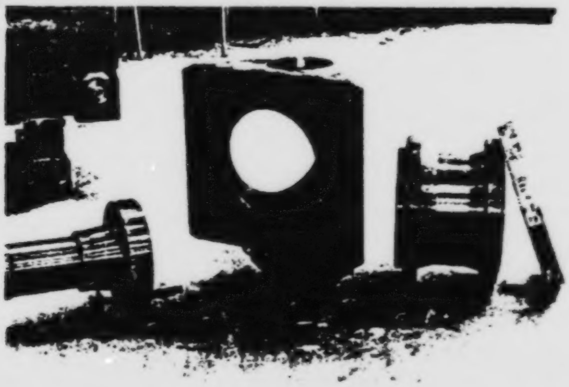
The console supporting the main frame is located underneath the main frame but above the yaw drive. At the top of the console four holes for the bolts of the main frame hinges are located. Further down a support for the reaction stay is located.

The main frame and with that the entire nacelle may be removed by removing the hinge bolts and the reaction stay. Remaining on the tower are the console and the yaw drive, mounted directly on the tower.

In order to avoid unwanted aerodynamic flow the nacelle has been made open. The nacelle has a set of hand rails for safety reasons.

2.2 Rotor and Hub.

The rotor hub is of a classical triangular welded type, intended for a three bladed rotor. The hub is bolted onto the forged flange of the rotor shaft. The blades acquired for the machine are 5 meter long of the make "KJ glasfiber", but the machine will accommodate blades up to 7,5 m length. The blades are mounted on measurement cylinders for the measurement of blade forces. There are also bearings for use in connection with blade pitch control.



The rotor hub measurement cylinder.

2.3 The Tower.

The tower height is 15.7 m, and the tower is built as a slender tube supported by guy wires. This design was chosen in an effort to minimize aerodynamic disturbances.

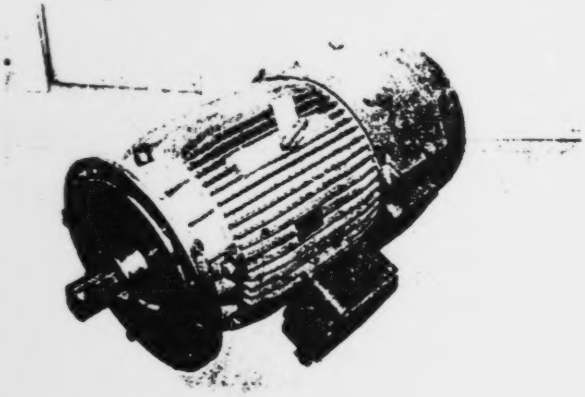
A four legged bottom frame is bolted onto an existing foundation. The distance from the tower of the guy wire mounting on the foundation may be varied.

The yaw drive mechanism is mounted below the tower top. It is supported by measurement stays for the measurement of yaw forces.

2.4 Electrical Equipment.

The research windmill is equipped with grid connection similar to standard grid connected windmills. The yaw dive is electrical and is a part of the grid connection.

The generator is a slip ring induction generator rated at 30 kW at 1500 rpm. Initially the slip rings will be short circuited, but later tests will be made with a "controlled soft" induction generator.

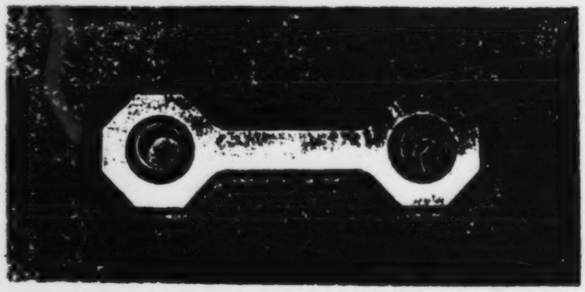


The asynchronous generator

The electrical equipment at the time of commissioning is only for operation of the machine. Later on measurement equipment will be added corresponding to the requirements of each R&D project.

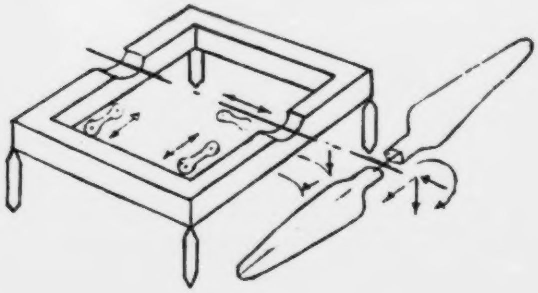
2.5 Measurement Transducers.

Measurements are made mainly with strain gauges that are connected to the Test Station's PDP 11 computer. Strain gauges are mounted on measurement stays, measurement cylinders and on the smooth part of the rotor shaft.



The measure stay

The locations at which measurements may be made are divided into primary and secondary locations. These will be instrumented at the commissioning of the machine. Furthermore, tentative locations may be instrumented later if need arises.



3 forces and 3 moments are absorbed by the 3 stayes

Primary locations are: 1) Measurement cylinders on the hub, gauges at an angle of 90° to each other for measurements of wind pressure, gravity forces and driving torque. (2) The smooth part of the rotor shaft between the hub and the front end main bearing. One axial and two radial gauges 90° to each other. (3) Three measurement stays for fixation of the rotor shaft frame. One axial and two radial gauges.

Secondary locations are: (1) Torque reaction stay on the gearbox. (2) Torque reaction stay on the generator. (3) Torque reaction stay on the yaw drive.

Tentative locations are: (1) Stays supporting the rotor shaft frame. (2) Support stay for the main frame.

3. R&D Projects for the Research Windmill.

A number of projects in the Test Station's R&D program have been proposed with the research windmill in mind. A detailed description of the projects is outside the scope of this paper. The projects may be divided into the following three subject groups:

3.1 Aerodynamics.

The research windmill is designed for the measurement of aerodynamic forces acting on a rotor, resolved into three force components and three moment components. Projects on computer code evaluation, yaw stability and stall control have been proposed and other projects are being shaped.

3.2 Structural Dynamics.

Dynamic forces and structural response may be measured for varying yaw error, power output, rotor rpm and structural stiffnesses. Projects on computer code evaluation, stall induced vibrations and two bladed rotor dynamics have been proposed and other projects are being shaped.

3.3 Other measurements.

The power train has several measurement locations. Projects have been proposed on power loss for each component and on power train dynamics during steady state operation and during cut-in and cut-out.

4. Status - August 1985.

Foundation and tower for the research windmill have been completed. Major components such as main and rotor shaft frames, hub, rotor shaft, measurement cylinders, reaction stays and brake disc are also completed. Major components such as gearbox, generator, bearings, blades and brake hydraulics have been purchased.

At the time of writing the nacelle is being assembled in the Test Station's workshop, and minor components are being manufactured or purchased.

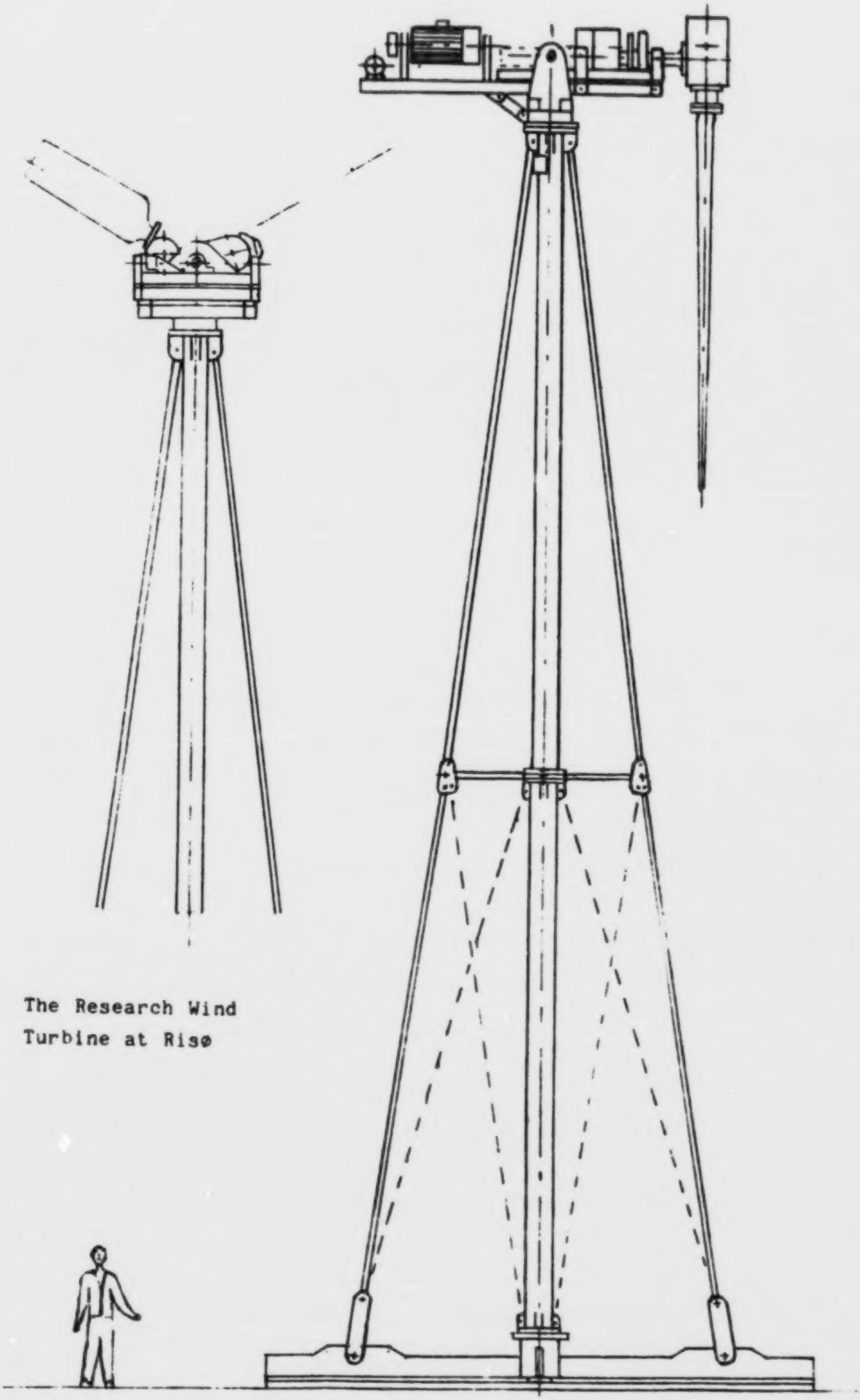
When the research windmill is finally assembled it will be subject to a standard test similar to other windmills at the Test Station. The instrumentation will be that of a standard test. After completion of the standard test the windmill is commissioned and the measurement programs can be started.

Acknowledgements.

The work described in this paper is sponsored by the Danish Ministry of Energy. The author wishes to thank Per Lundsager for his support in writing the paper.

Hub height	16.6 m
Tower height	15.7 m
Tower diameter	0.324 m
Distance from Hub to tower centerline	2.0 m
Generator:	
Type	Induction Slipring
Synchronous rpm	1500
Stator power	30 kW
Rotor power	30 kW
Gearing:	
gearbox	1:19.9
Belt drive	Adjustable
Rotor diameter	11.5 m
Number of blades	3
Blade length	5.0 m
Tilt angle	- 2 ÷ 10 deg.

Table 1: Main data for the research windmill.



The Research Wind Turbine at Risø

International Meeting of Test Stations for SWECS
Prince Edward Island, Canada, August 21-23, 1985

Spectra of wind power and electrical power output

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The ability of a wind turbine to react on wind speed variations is determined by its overall inertia, a measure of which is the turbine's cut-off frequency. To determine the cut-off frequency 1 s averages of wind speed and instantaneous values of electrical power output were sampled at 1 s intervals for the MAN turbine 'Aeroman' while 0.5 s averages were used for the WINDMATIC wind turbine. Three times 4096 data points were spectrally analyzed using Fourier transformation. The spectra of the input, wind power (u^3), and the output, electrical power (P), normalized by their variances, are shown in fig. 1 (MAN) and fig. 2 (WINDMATIC). In fig. 1 the higher turbulence intensity during run 2 is evident from the u^3-spectrum.

The spectra can easily be divided into three parts. For run 1 of fig. 1, as an example, the P-spectrum follows the u^3-spectrum quite well at frequencies < 0.07 cps, the first cut-off frequency f_1. In the frequency range $0.07 < f < 0.2$ cps, the second cut-off frequency f_2, the similarity is lost. This is due to the smoothing of several geometrically small eddies which pass the rotor at the same time and which balance each other. In this region the P-spectrum is not only lower than the u^3-spectrum but also independent. Wind fluctuations above 0.2 cps pass through the rotor area without affecting the turbine.

The cut-off frequencies and the mean wind speed during the run may be combined to a response length $l = u/f = 123$ meter or 44 meter for f_1 or f_2, respectively. The corresponding data for run 2 of the MAN and for the WINDMATIC are given in table 1.

Table 1: Specific data of the spetra in fig. 1 and 2

$\bar{u}$: mean wind speed

$\bar{p}$: mean electrical power output

$f_{1,2}$: cut-off frequency 1 or 2

$l_{1,2}$: response length

	MAN run 1	MAN run 2	WINDMATIC
$\bar{u}$	8.8 m/s	10.5 m/s	8.5 m/s
$\bar{p}$	10.7 kW	14.5 kW	8.7 kW
f_1	0.07 cps	0.04 cps	0.1 cps
f_2	0.20 cps	0.20 cps	0.4 cps
l_1	123 m	262 m	85 m
l_2	44 m	52 m	21 m

Because of its heavier construction elements in comparison to the MAN the WINDMATIC wind turbine was expected to have a greater moment of inertia and consequenty a lower cut-off frequency. The data in table 1 show the opposite. The operating status indicated by the mean power output at which the spectra were measured seems to determine the overall inertia of the turbine. Both machines operate at a constant number of revolutions per minute but the load and thus the torque rise with increasing wind speed and consequently the inertia of the turbine increases. Therefore, a comparison of cut-off frequencies or response length of different wind turbines is meaningful only if the spectra are taken at the same state of operation. For the considered machines the best point for such measurements is the wind speed at which the power curves intersect (fig. 3). A graph showing the response length as a function of power output and wind speed is thought to be an important information for wind turbine judgement.

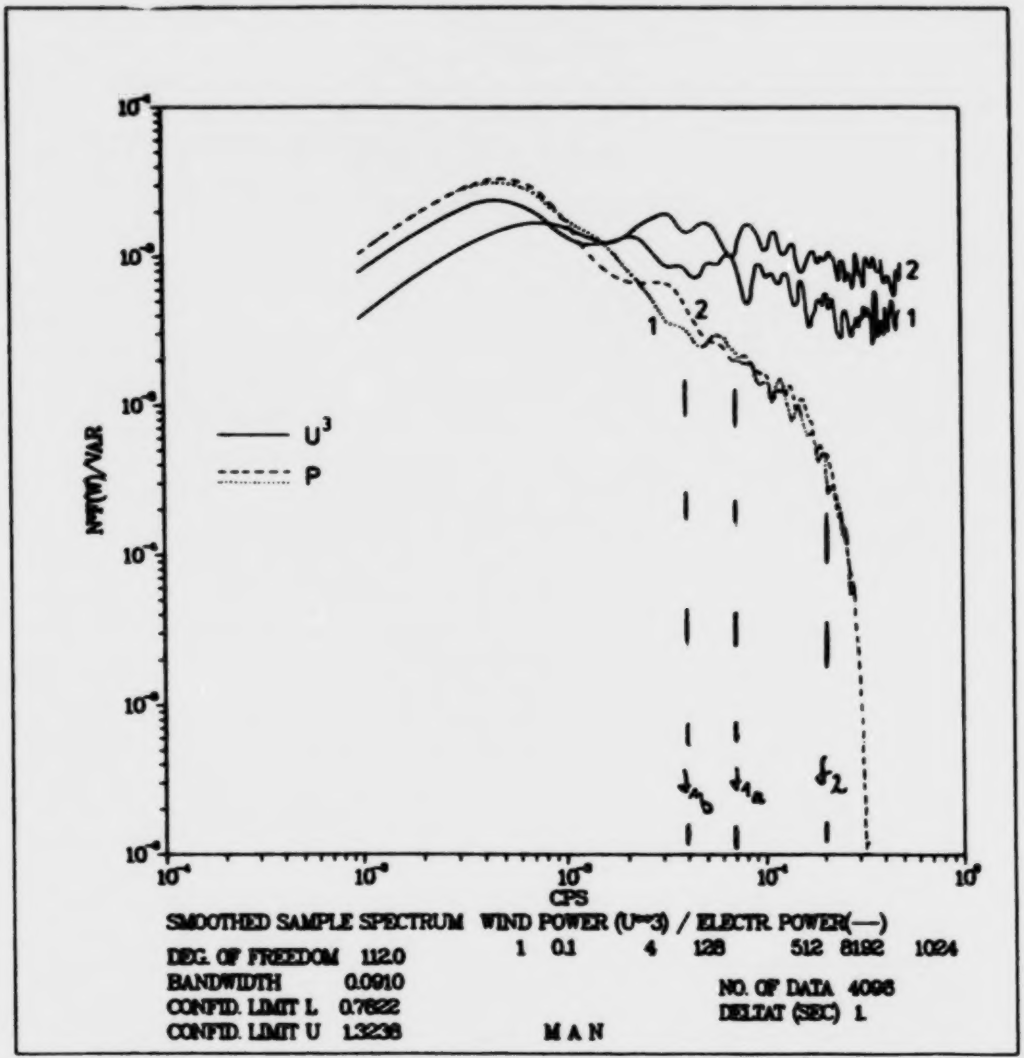

Figure 1: Spectra of wind power (u^3) and electrical power (P) of the MAN wind turbine. The spectra are plotted in the form log (frequency * spectrum/total variance) vs log (frequency). The sampling interval is 1 s.

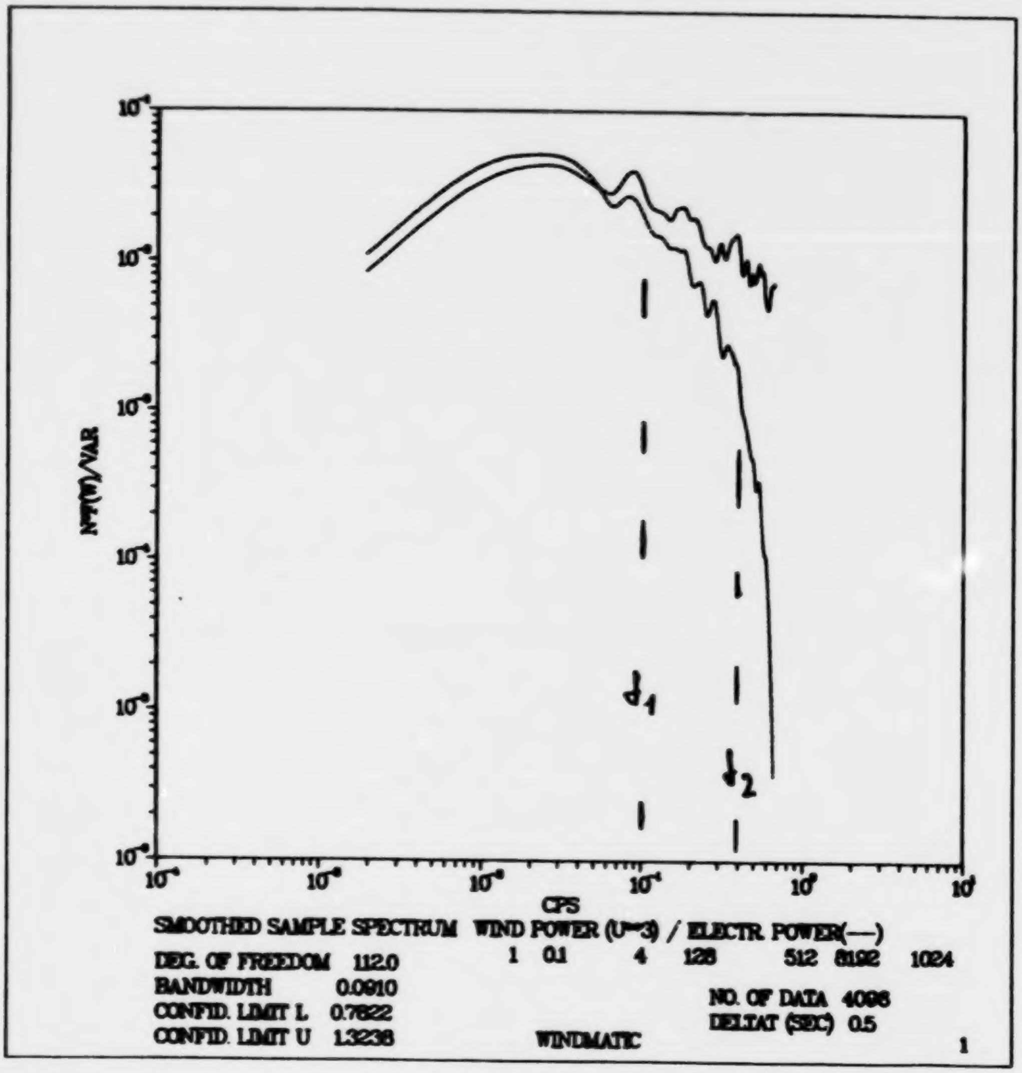

Figure 2: same as fig. 1, but for the WINDMATIC wind turbine. The sampling interval is 0.5 s.

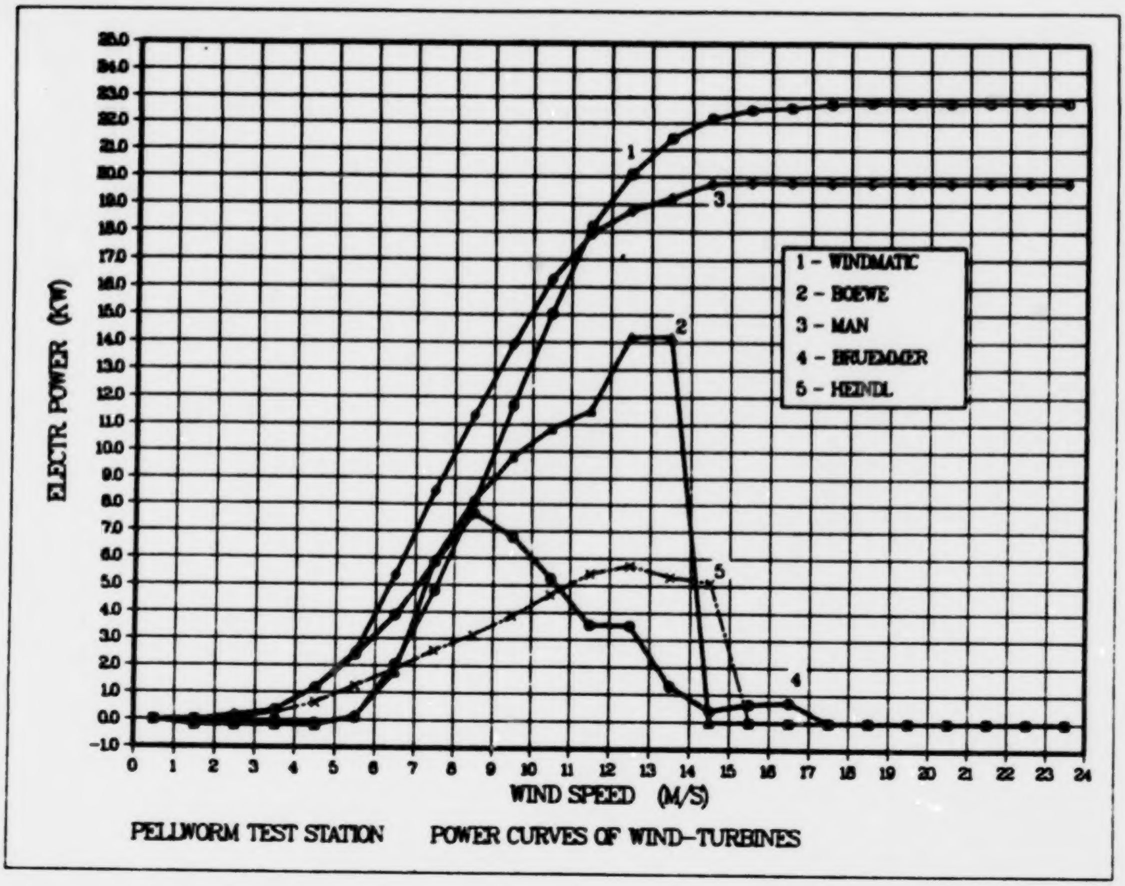

Figure 3: Electric power as a function of wind speed for 5 wind turbines.

Some results of rotor blade measurements

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Summary:

At the German test field for wind energy converters, operated by the DFVLR at Schnittlingen in the South of Germany, some statistically evaluated measurements were taken on rotor blades. In addition a correction method for the power measurement is shown which is different to the IEA recommendation.

1. Power Measurement Correction Method

The German test field for small and medium sized WECs is located on the top of a ridge of the Schwäbische Alb in Southern Germany. 732 m altitude above see level had to be taken into account for the correction of the measured power output of the WEC. The changes in atmosphere pressure for most of the test sites is normally only given by the weather conditions, because the site altitude doesn't differ much from sea level. Therefore the power corrections done on the DFVLR test field shows more significant differences between measured and corrected values. This effect and the testing of pitch controlled WECs brought up the necessity of a correction method different to the IEA recommendations. (1)

Pitch controlled WECs normally control the generator output. This power limit is independent on the fact how it is aerodynamically generated, by high wind and low air density or by low wind and high air density. An IEA based correction of a pitch controlled WEC therefore leads to higher power outputs than the power limit given by the control system. To avoid this the IEA recommends to set all corrected power values higher than rated power equal to rated power. But this cannot be a satisfying solution because for 10 min averages between

70 and 100 per cent of rated power pitch controlled power limitations occur with their influence on the average value. Therefore we propose to use wind speed corrected values instead of power corrected ones. For a given power output average it is assumed that the measured wind speed frequency distribution which led to the power output occurs also for the standard atmosphere conditions multiplied by a factor which compensates the effect of the density deviation.

$$v_{SA} = v_M \sqrt[3]{\frac{\rho_M}{\rho_{SA}}}$$

With index SA for standard atmosphere and index M for measurement values. Using this method the correction doesn't lead to power outputs higher than the maximum power which is given by the control system. (Fig. 1)

This correction method is only valid, when C_p is assumed to be nearly equal for the measured and the corrected wind speed. The reason is that in reality the WEC would operate under the corrected wind speeds with other tip-speed ratios and therefore of course also with other power coefficients. During pitch controlled power operation this is no longer important and in the power range nearly rated power the power coefficient doesn't change very much because it is near to the wide ranged flat optimum of the C_p-curve. The main advantage of that correction method is that the asymptotic approach to the rated power, which is dependent on the power control quality, can be maintained and will not be cut-off by the artificial power limit introduced by the IEA recommendation.

2. Acceleration Measurements at the Blade Tip

In one of the tested WECs accelerometers were mounted at the blade tips to measure accelerations and vibrations in-plane and out-of-plan of the rotor.

Fig. 2 shows the in-plane accelerations taken at the blade during a synchronization with the grid. The basic acceleration is a ± g load caused by the rotor rotation combined with some higher vibrations. At the moment of synchronzation a ± 10 g acceleration fluctuation between negative and positive bending during one revolution of the rotor blade. With increasing wind speed the most frequent bending becomes smaller and the range of values larger.

Fig. 8 and 9 represent the average load increase dependent on the average wind speed and the average output respectively.

5. Drag measurement of the rotor blade

Some of the load cases which are used by DFVLR depend on the drag of the rotor blade when it is facing the wind with its largest cross area. Very few drag measurements under real conditions are available up to now and therefore DFVLR made some measurements under real conditions on the test field to verify the assumed drag coefficient of $C_D = 2.0$ which was used in the load cases. Under the assumption that at all sections of the rotor blade occurs the same drag coefficient an overall drag coefficient for the rotor blade could be calculated by the measured out-of-plane bending moment. The two measurement points at the root and at half length of the blade taken at the test field under real wind conditions corresponded very well to the load which was applied by a continous load distribution of sand sacks during the blade test in the laboratory, which was calculated by a constant drag coefficient along the blade. The resultant drag coefficient calculated by the wind loads became $C_D = 1.7$ instead of the assumed one of 2.0.

DFVLR intends to take more measurements on the drag behaviour of blades to find out the drag dependences on the shape and the twist.

References:

N N Recommended practices for wind turbine testing.
1. Power performance testing. 1. Edition 1982.
International Energy Agency

was measured which led to a damped vibration with a natural frequency of about 20 Hz. Strain measurements taken at the blade root at the same instant didn't show any significant increase of the structure load due to the high accelerations. The force measured in the pitch control rod shows similar frequencies to those measured at the blade tip (Fig. 3), but the highest changes in force occured, when the accelerations at the blade tips already were damped out. The origin of the frequency is not quite clear. May be that they are higher harmonics of the blade excited by some chock loads like sudden pitch control by the hydraulic system or the vibrations of the drive train.

3. Load Measurements at the Pitch Control Rod

The measurements at the blade pitch control rod shown in Fig. 4 and 5 were taken under different conditions. In Fig. 4 the rotor disk faces the wind perpendicular and in Fig. 5 under an inflow angle of 45°. For each bin of 10° azimut angle all data were averaged and are represented by the crosses in the graph. It is interesting to see that in both cases the force direction in the rod changes from tension to compression during one average revolution of the blade. Although the average wind speed for the oblique flow condition is 1,5 m/s lower than in case Fig. 4 the absolute size of the forces is higher. In addition the symmetry of the graph is turned by about 35°.

4. Bending moments in the rotor blade

The in-plane bending moment, measured at the root of the blade, shown in Fig. 6 corresponds to the case in Fig. 4. Under the relative high wind condition of 10.5 m/s the in-plane bending moment is positive for all azimut positions of the blade, e. g. the driving aerodynamic force is able to lift the rotor blade on its way up against the gravity force. The graph shows the frequency distribution of in-plane and out-of-plan bending moments during the measurement interval. A comparison between Fig. 6 and 7 indicates the significant load differences between the load behaviours under 4 m/s and 10.5 m/s average wind speed. Specially the in-plane bending moments at low wind show a

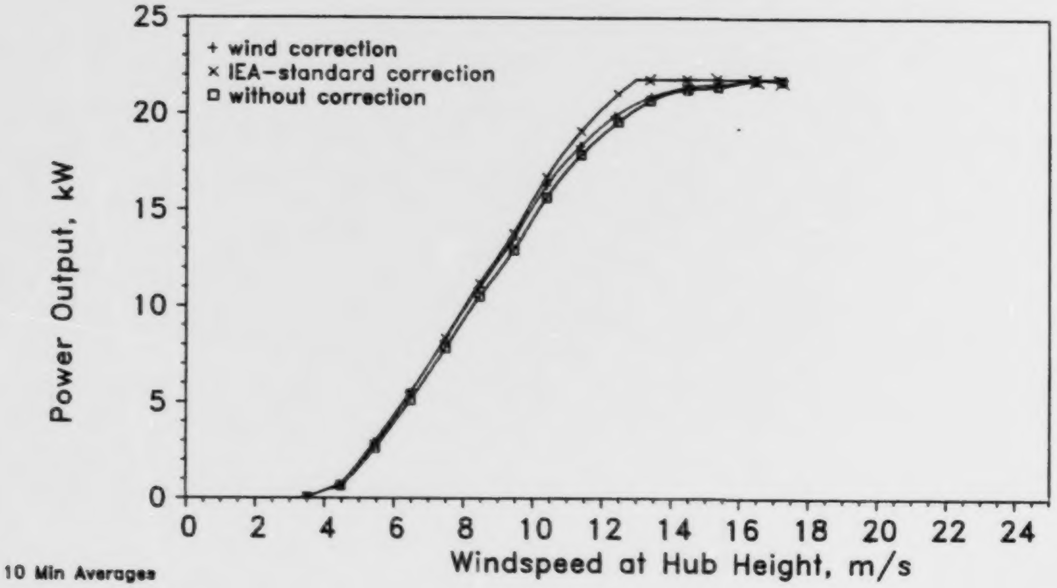


Fig. 1 Comparison of uncorrected power data with those corrected by IEA recommendations and DFVLR wind correction for a pitch controlled WEC.

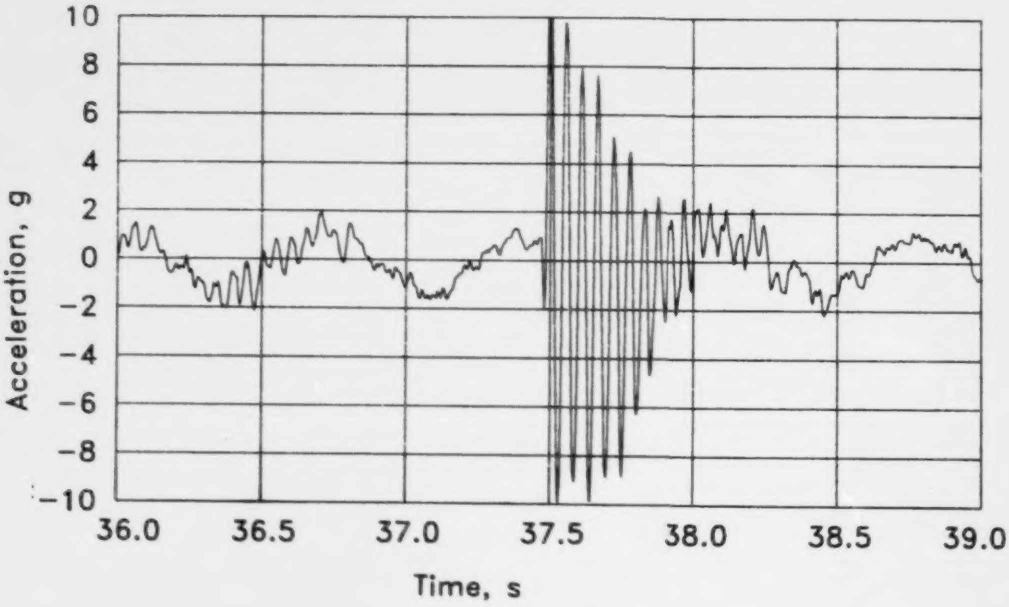


Fig. 2 In-plane accelerations measured at the blade tip during synchronization (time 37, 45 s) with the grid.

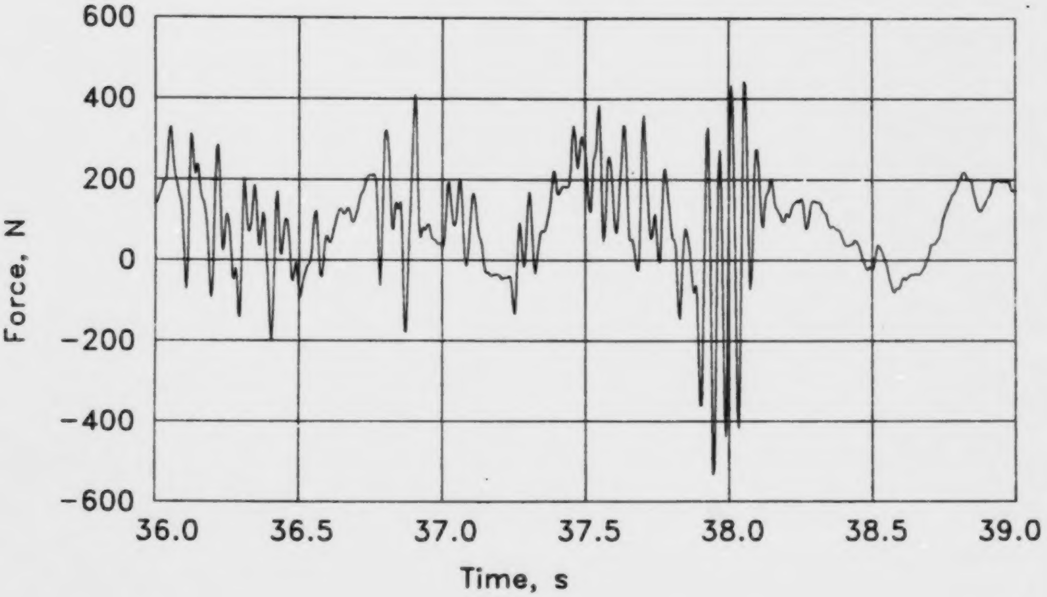


Fig. 3 Reaction of the second forces in the pitch control rod during synchronization (time 37, 45 s) with the grid.

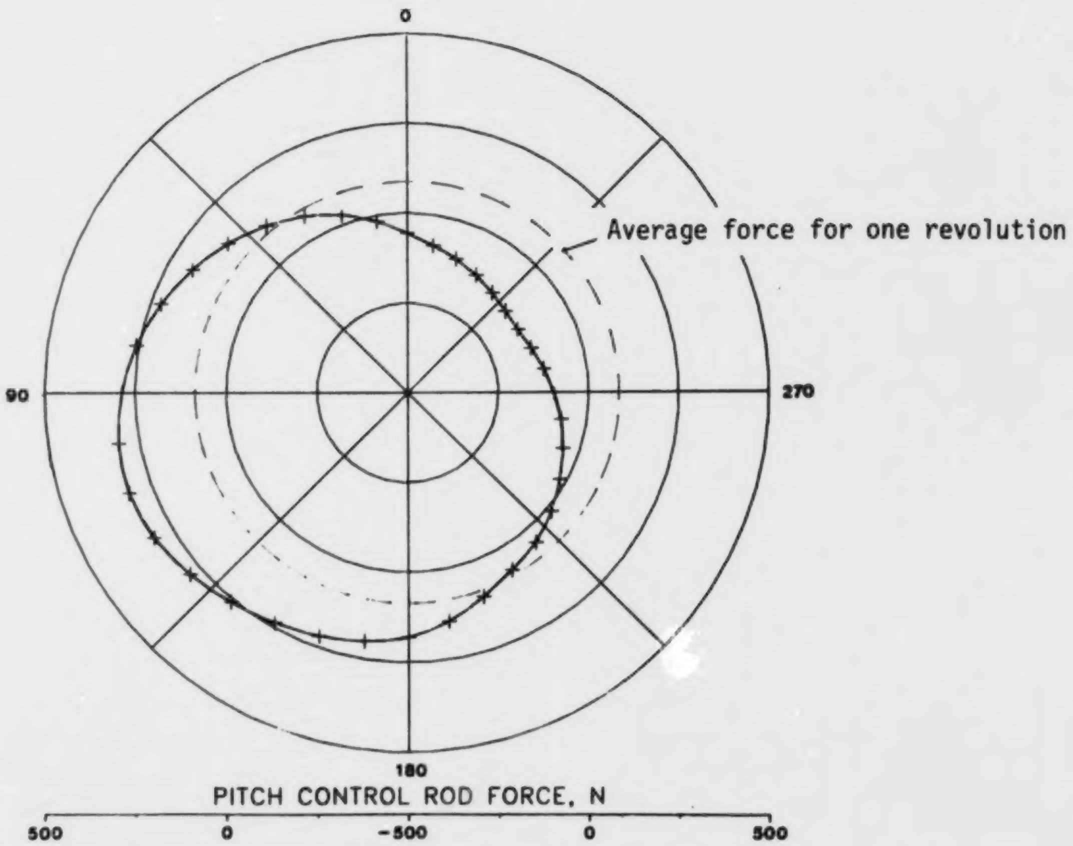


Fig. 4 Average normal force in the pitch control rod during one revolution of the blade under 10.5 m/s wind speed and rotor perpendicular the air flow.

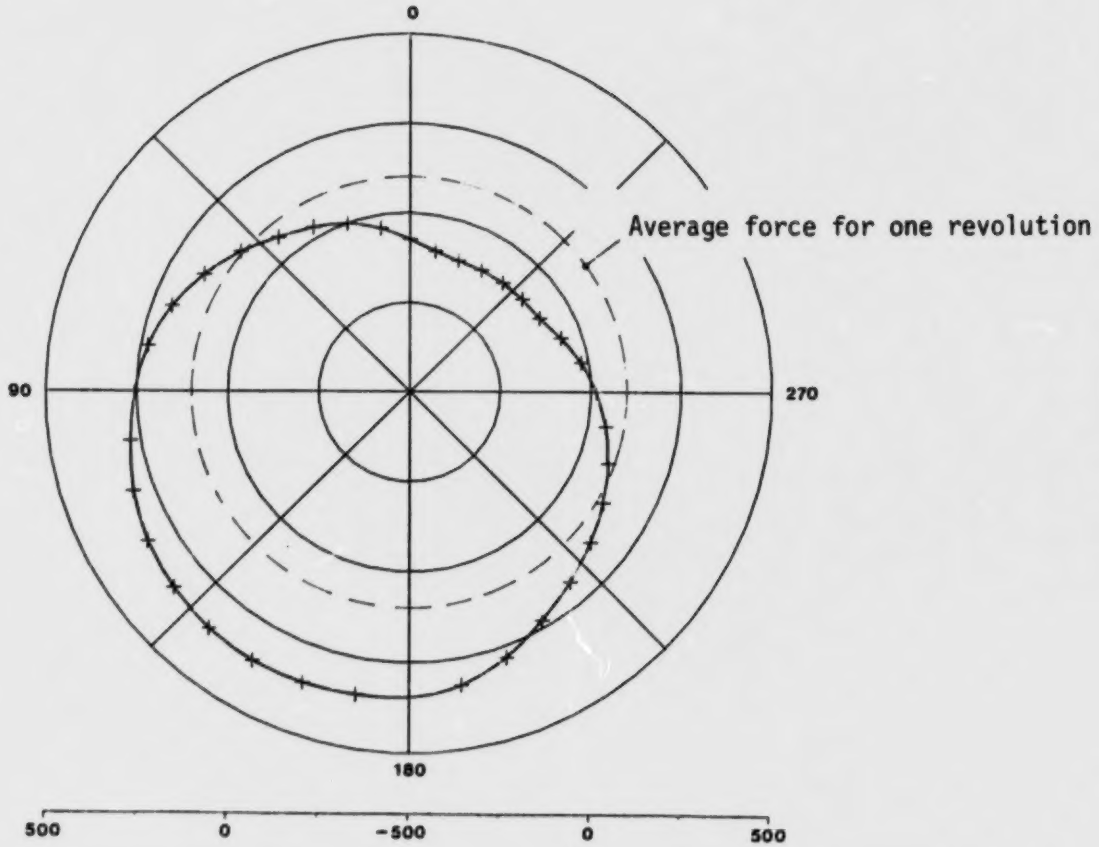


Fig. 5 Average normal force in the pitch control rod during one revolution of the blade under 9 m/s wind speed and rotor 45° oblique to the air flow.

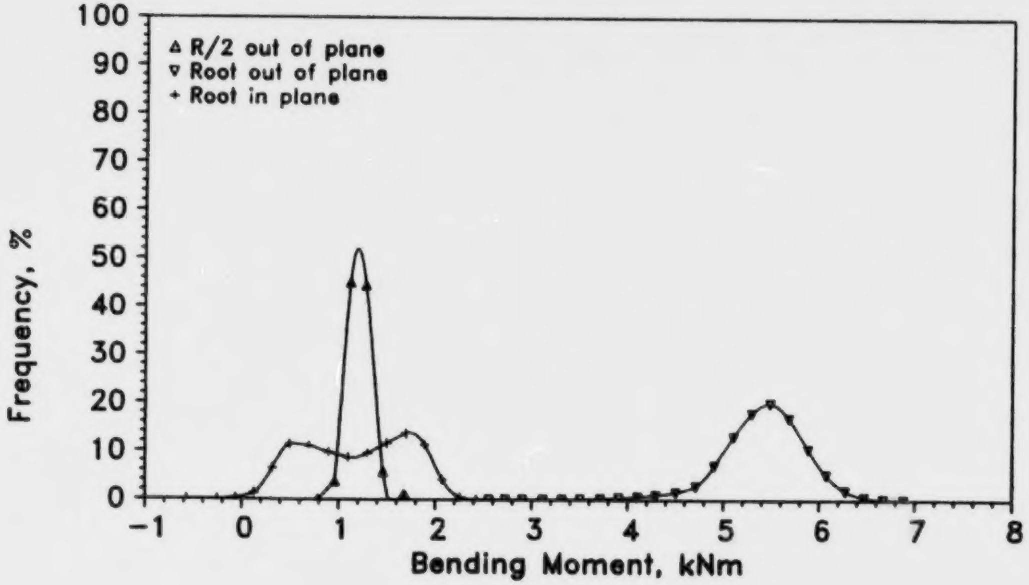


Fig. 6 Frequency distribution of bending moments in the rotor blade under an average wind speed of 10.5 m/s.

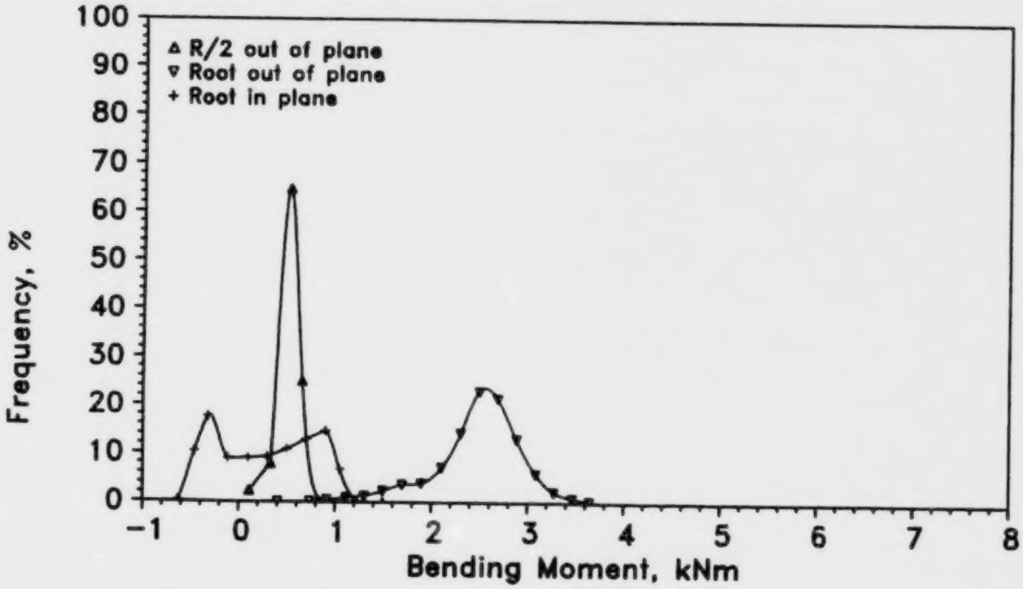


Fig. 7 Frequency distribution of bending moments in the rotor blade under an average wind speed of 4 m/s.

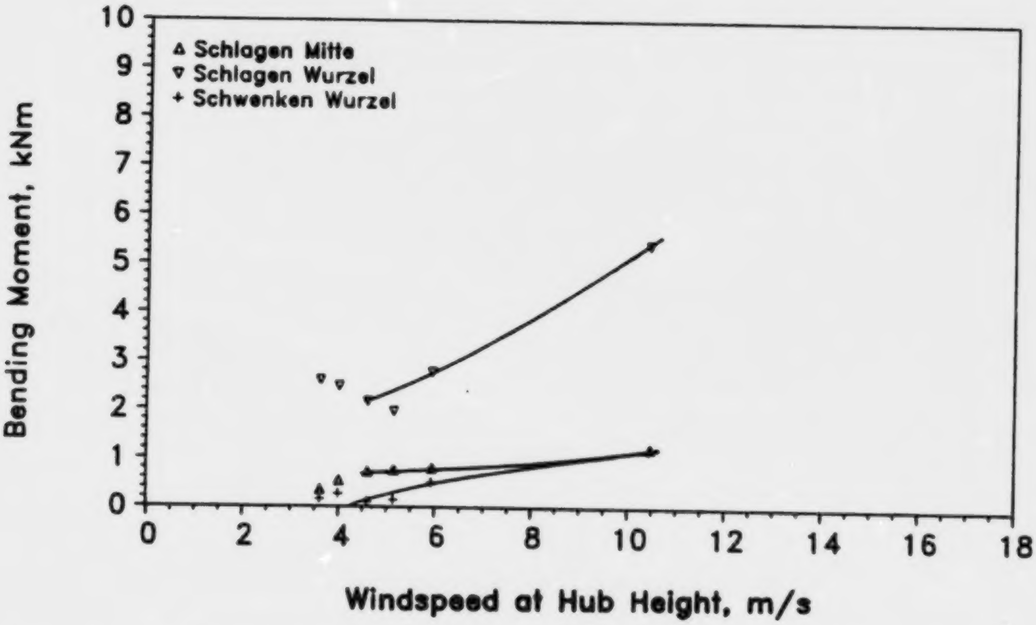


Fig. 8 Average bending moments in the rotor blade related to the average wind speed at hub height.

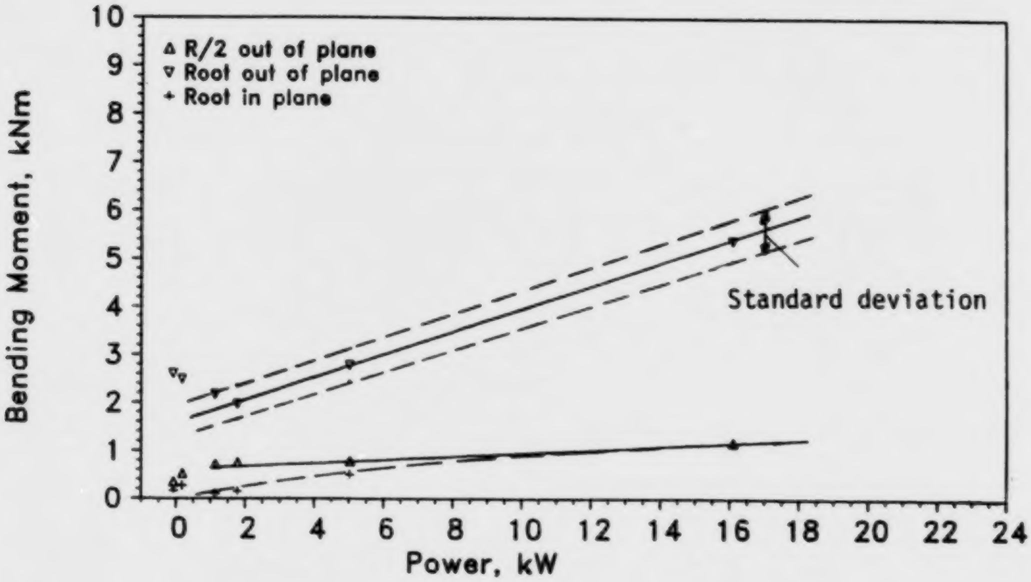


Fig. 9 Average bending moments in the rotor blade related to the average power output of the WEC.

ITALIAN TEST SITES

G.Gaudiosi ENEA-FARE CRE CASACCIA ITALY

PREFACE

Since 1982 it was recognized the necessity to have a National Test Center for the technological development and testing of the small, medium size wind machines.

ENEL started by the Santa Caterina test site (in South West Sardinia), where up to now about five wind machineshave been tested.

For grid connection:

- the horizontal axis, three blades, 68 kW unit developed by FIAT in 82
- two horizontal axis, two blades, 20 kW unit of GRUMMAN (USA), modified by Aeritalia in 82.

For isolated users:

- the orizontal axis, two blades 20 kW developed by Aeritalia (83); the h. axis monoblade 3 kW developed by RIVA Calzoni (84).

The Santa Caterina Site has good wind characteristics, but it is perturbated by the presence of a tall building to be destroied.

ENEA has planned a national test Center. Many sites in Italy have been analized.

Up to now some areas have been found in South Italy (Sardinia, Sicily, Puglia). Sardinia has good chances.

A possible collaboration has been envisaged with ENEL and the industry for the National test Center. A decision will be taken in 1986.

Meantime ENEA is using its Energy Research Center of CASACCIA, with a moderate seasonal wind regime (good in winter), to test a 3 kW monoblade Riva Calzoni, and one additional small turbine : a SALMINI 100W for bactery charge. Moreover, in 1,986, will be tested a Celotti .15 kW horizontal axis unit. A water pumping system will be added later in the same year with electric transmission. A multiplade wind piston pump has been tested before for irrigation applications.

Another test site has been operated until 1984 by AGIP (ENI Group) at Segezia (Puglia), where 3 wind machines are under test: a 0.5 kW wind machine for charge of electric bactery, developed by Salmini, a 60 kW AXIAL/EN.EO horizontal axis, twoblades wind machine for grid connection ad a vertical axis 9 kW system mechanically coupled to a Diesel generator.

Up to 1984 the Berceto site (North Appennin) has been used by the Axial company for testing a 100 kW wind machine for grid connection.

Finnally during 1983 a 5 kW Darrieus type, vertical axis machine has been tested by CESEN under E.C. and ENEA contract at Passo del Turchino close to Genova.

1 - Small size wind machines (Rotor diameter <15m)

Small wind machines may be used for the production of mechanical or electric energy for isolated users, usually coupled with suitable storage systems.

The fundamental requisite is a high operating reliability in any meterological condition, with the necessary periodic inspection and maintenance, by nonspecialized personnel, reduced to a minimum.

This feature requires a considerable engineering commitment in design and technological development, only available by large organizations.

Therefore, small industry, the most interested in such low power range, should be helped by major public bodies (ENEA, ENEL, PFE) to compete at the same level with North American and European builders, more advanced in the sector.

About 11 wind machines are in various stages of technological development in Italy; Table A1 gives a summary of their characteristics and application.

There are many Italian firms specialized in the production of mechanical and electric components of good quality and low price.

2 - Intermediate size Machines (100< Power <500kW)

This wind machines are intended for connection to small or large electric

grids.
In Italy application for this machines rapresents only the first phase of wind energy penetration in the next 5-6 years, then developed large wind generators will be available for power use.
Two feasibility studies have been carried out in 1982 under ENEA contracts: a vertical axis, Darrieus type machine of 150 kW by CESEN and a horizontal axis, 200 kW by AERITALIA.
In 1984 a contract for the construction of a 200-300 kW horizontal axis, two blades, up wind (32 m Rotor diameter) wind turbine MEDIT (MEDITERRANEUM MACHINE) has been awarded by ENEA to AERITALIA. The machine will be located by the beginning of 1986 at ALTA NURRA site of ENEL (North Sardinia).
ENEL will partecipate to the machine operation.
Recently (october 84) the EUROPEAN COMMUNITY (EC) has partially financed the MEDIT program particulary for test and data analysis.
An additional medium size machine have been partially finanzed by EC:

- the monoblade horizontal axis, up wind (25 m in Rotor diameter) MP22 developed by RIVA CALZONI.

The sites for the above machine could be the ENEL Alta Nurra Area or optionally sites in South Italy (Puglia, Abruzzi, Sicilia).
Financial integration to EC support for the construction costs could be provided by ENEA.
A horizontal axis, two Aluminium extruded blades, 180 kW unit has been developed for California market by a private Company Axial/EN.EO, now out of market.
The strong effort for the development of the intermediate size range machines is particularly due to the booming market in the USA, and recently in North Europe.

3 - Wind parks

The only existing wind Park in Italy is the 500 kW, ENEL Plant in Alta Nurra (North Sardinia), cointaining 10 machines of 50 kW . developed by FIAT/ENEL in the last two years. The unites are connected to the Sardinia electric grid.

An additional 600 kW wind park is foreseen in Pantelleria (a small island of Sicily) composed by 5 units of 50 kW FIAT and 5 of 70 kW FIAT industrialized version of a 68 kW under test at the ENEL SITE of Santa Caterina (South Sardinia).

The 10 units should be connected to the Pantelleria electric grid fed by Diesel generators.

The project is still under discussion.

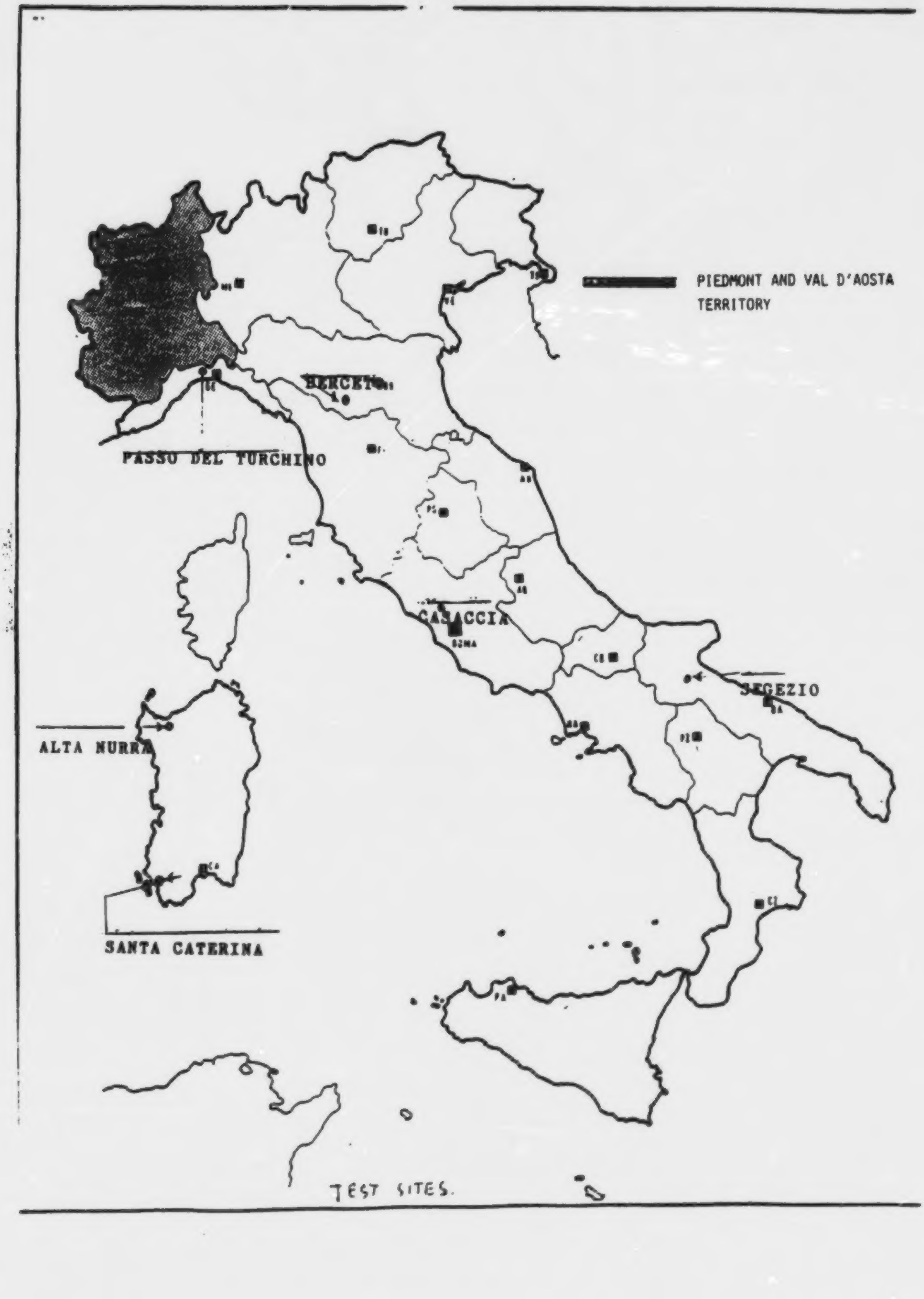
CONCLUSION

Up to now many sites have been used for testing wind machines at high operating cost. It has been then recognized the necessity to have only one national test site.

ENEA and ENEL, possibly together should decide in 1986 the set up of such enterprise in a site of ENEL (Santa Caterina) or in a different area of South Italy.

The further needs to test wind systems for developing countries give additional pressure particularly to the above ENEA decision.

MAP OF ITALY


PIEDMONT AND VAL D'AOSTA TERRITORY
BERCETO
PASSO DEL TURCHINO
CASACCIA
ROMA
SEGEZIO
ALTA NURRA
SANTA CATERINA

TEST SITES.

LOCALITA'	PROVINCIA	STAZIONE DI RILEVAMENTO	PERIODO DI RILEVAMENTO	VELOCITA' MAX (m/s)	VELOCITA' MEDIA ANNUA (m/s)	FREQUENZE CALME	NOTE
OTRANTO "La Palascia"	LE	Stazione A.M. "La Palascia"	Dal Dic. 1969 al Nov. 1977 (+)	31 (*)	6 6,20 senza calme	10%	(+) Elaborazioni su dati ISTAT (*) Medie delle massime nel periodo di rilevamento
OTRANTO "Consalvi"	LE	Riferimento Stazione A.M "La Palascia"	1960 + 69 (+)	37,5	7 7,40 senza calme	5%	(+) Elaborazioni dati CNR
SANTA CESAREA	LE	Riferimento Stazione A.M. "La Palascia"	1932 + 62 (+)	(*)	6,9	3%	(+) Elaborazioni dati IMM (*) Registrazione di valori 32 m/s durante le burrasche
MONTE S.ANGELO	FG	Riferimento Stazione A.M. "Monte S.Angelo"	Dal Dic. 1969 al Nov. 1979 (+)	38,8 (*)	6,20 7,2 senza calme	14%	(+) Elaborazioni dati ISTAT (*) Medie delle massime nel periodo di rilevamento
TREVICO	AV	Riferimento Stazione A.M. "Trevico"	Dal Dic. 1969 al Nov. 1979 (+)	31,2 (*)	5,95 6,9 senza calme	14%	(+) Elaborazioni dati ISTAT (*) Medie della massime nel periodo di rilevamento
CANDELA	FG	Riferimento Stazione A.M. "Candela"	1960 + 69 (+)	43,61	5,51 6,16 senza calme	10,5%	(+) Elaborazioni dati CNR

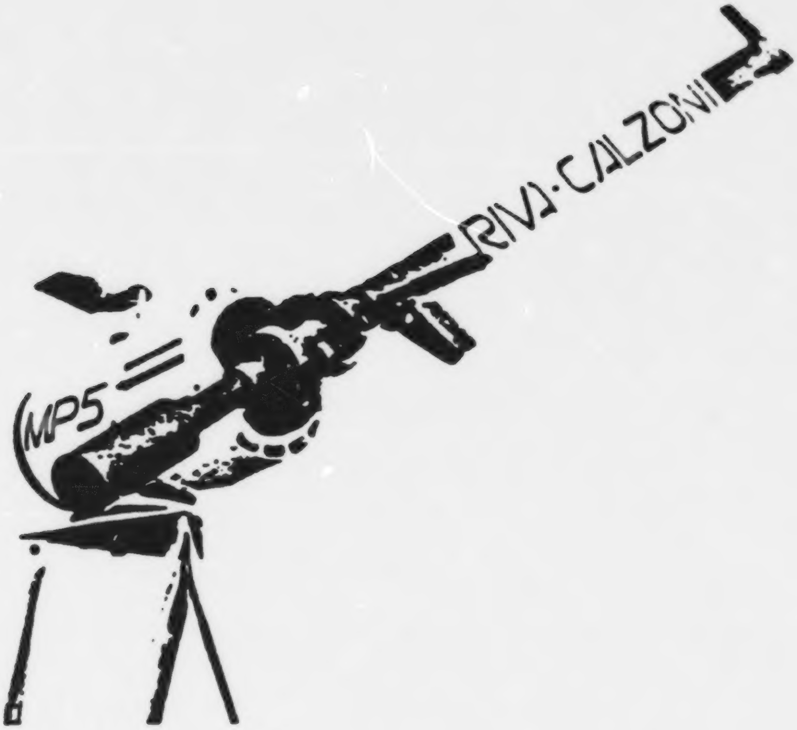
1. SCHEDA ANEMOLOGICA

LOCALITA'	PROVINCIA	STAZIONE DI RILEVAMENTO	PERIODO DI RILEVAMENTO	VELOCITA' MAX (m/s)	VELOCITA' MEDIA ANNUA (m/s)	FREQUENZE CALME	NOTE
ARGENTIERA	SS	Stazione mobile ENEA	1. 7. 83 4. 9. 83 (+)	11,9 (*)	4,9 (°)	12%	(+)Rilevamento effettuato dalla Stazione Astronomica (*) Media delle massime diurne (°) Medie nel periodo ri rilevamento
S. ANTONIO DI SANTADI	OR	Riferimento Stazione A.M. "Capo Frasca"	1969 - 1978 (+)	29,4 (*)	5,1 5,8 senza calme	12%	(+)Dati Stazione Astronomica di Cagliari (*) Media delle massime nel periodo di rilevamento
PESCINA REI	CA	Stazione mobile ENEA	25. 8. 83 20.10. 83 (+)	8,9	3,2	25%	(+) Rilevamento effettuato dalla Stazione Astronomica
PORTODOTTE	CA	Stazione mobile ENEA	7. 6. 83 9. 7. 83 (+)	12,4 (*)	5,2 (°)	10%	(+) Rilevamento effettuato dalla Stazione Astronomica (*) Media delle massime diurne (°) Media nel periodo di rilavamento
SANTA GIUSTA	OR	Riferimento Stazione ENEL "Cirras"	1982 (+)	19,4	5,8 4,3 (°)	7,92	(+) Dati ENEL Elab. Stazione Astronomica (°) Dati ENEL periodo Giugno 80 - Agosto 82

2. SCHEDA ANEMOLOGICA
(Sardegna)

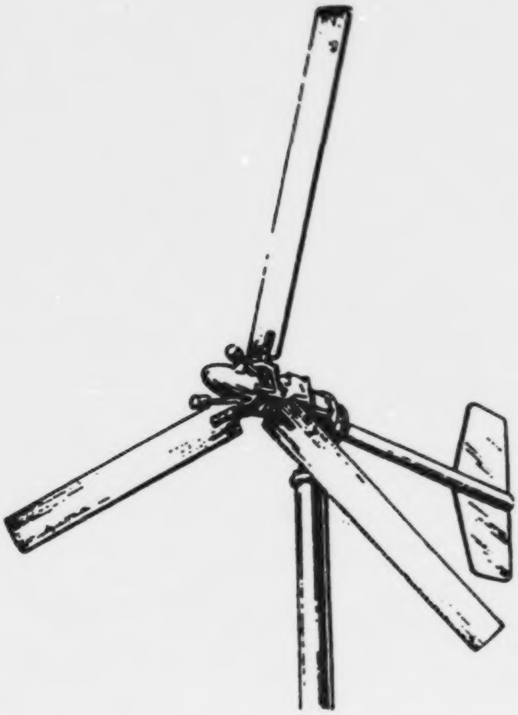
LOCALITA'	PROVINCIA	STAZIONE DI RILEVAMENTO	PERIODO DI RILEVAMENTO	VELOCITA' MAX (m/s)	VELOCITA' MEDIA ANNUA (m/s)	FREQUENZE CALME (%)	NOTE
SANTA CATERINA	CA	ENEL	Genn. 81 Luglio 83 (+)	24 (*)	5,2	25%	(+) Dati ENEL (*) Media nei 10 minuti
UNIA	SS	ENEL	Dic. 79 Luglio 83 (+)	22 (*)	4,8	18%	(+) Dati ENEL (*) Media nei 10 minuti
PORTO TORRES	SS	Possibili riferimenti alla Stazione di UNIA					
BORGO SEGEZIA	FG	Indicazioni possono aversi dalla Stazione A.M. di Candela					Dati eolici rilevati sul posto in via di elaborazione da parte AGIP
ORBETELLO	GR	Riferimento Stazione A.M. Monte Argentario	1969 - 79 (+)	33 (*)	4,59 5,36 senza calme	13%	(+) Elaborazioni dati ISTAT (*) Media delle massime nel periodo di rilayamento
RADICOFANI	SI	Riferimento Stazione A.M. Radicofani	1969 - 79 (+)	33,12 (*)	5,45 6,63 senza calme	17,5%	(+) Elaborazioni dati ISTAT (*) Media delle massime nel periodo di rilavamento

3. SCHEDA ANEMOLOGICA
(Località proposta nel G.d.L. MICA)



Type	Horizontal axis, with upwind rotor
Rotor	Single blade, with variable pitch and feathering
Hub	Teetering
Control system	Mechanical
Transmission	Direct drive
Generator	Three-phase synchronous generator, with built-in AC/DC rectifier, 110 V DC
Tower	Cylindrical steel shell, stiffened by two 90° guys
Total weight	~ 300 kg (above tower)
Rotor diameter	5.3 m
Hub height	12 m
Wind speed (at hub height)	
- cut-in	~ 3 m/s
- rated	9 m/s
- cut-out	18 m/s
Rated power	3 kW

- "Riva Calzoni MP5" 3 kW wind-turbine generator

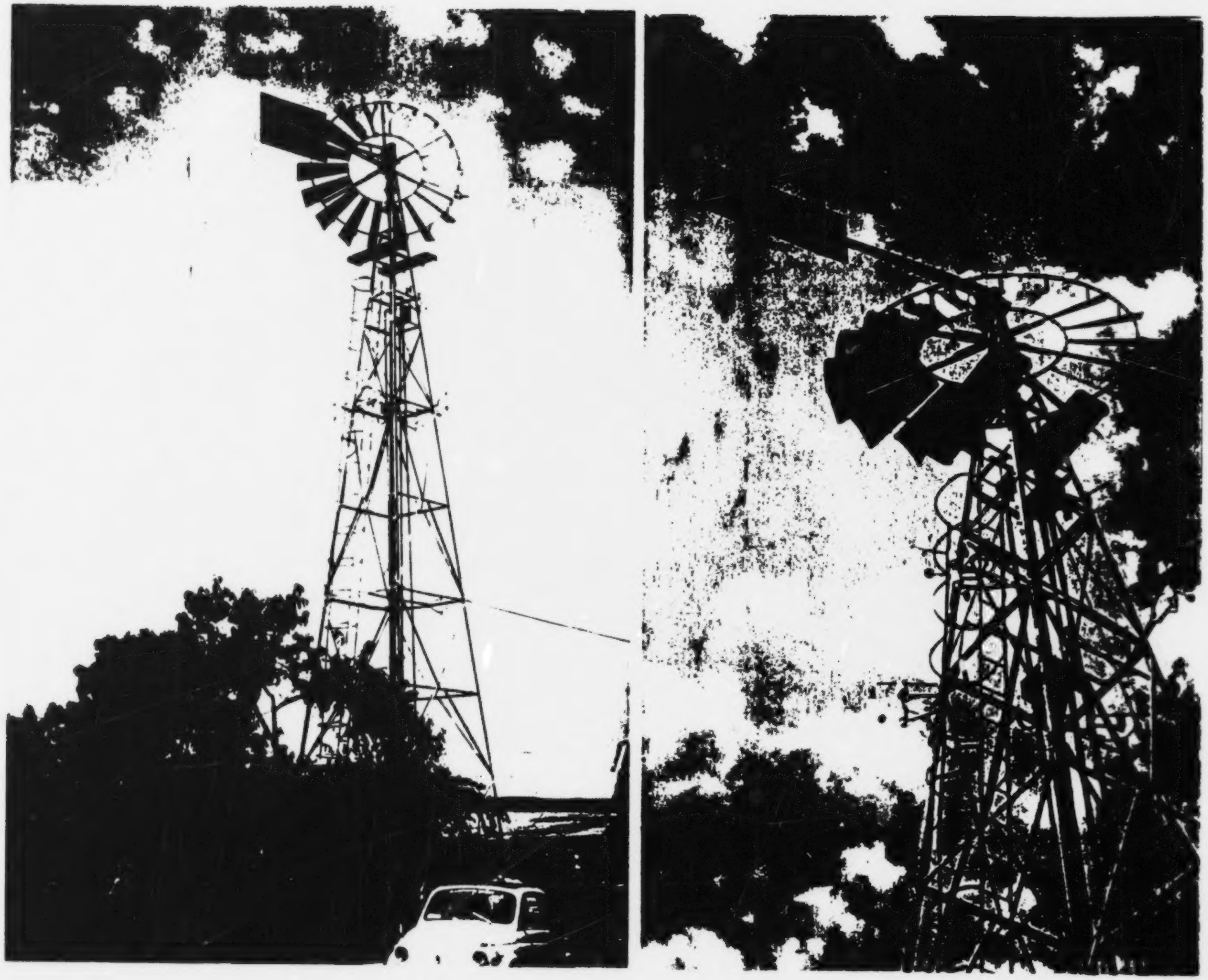


WIND GENERATOR "LIBELLULA"

Main characteristics

Type	horizontal axis - upwind with tail
Rotor	three blades - variable pitch diameter 4 m.
Governor	centrifugal with three pitch steps: starting, normal operation, high winds
Step up gear	one step ratio 4 : 1
Generators	two synchronous 96 V, variable frequency, one 1 kW, one 2 kW
Starting wind speed	4 . m/s
Design wind speed	12 m/s
Design power output	3 kW
Third governing step wind speed	12 m/s
Tower	steel tubular, braced
Weight rotor and nacelle	160 kg
Electrical auxiliaries	rectifier storage batteries electronic governor inverter

AIT 03 AERITALIA - GRUMMAN



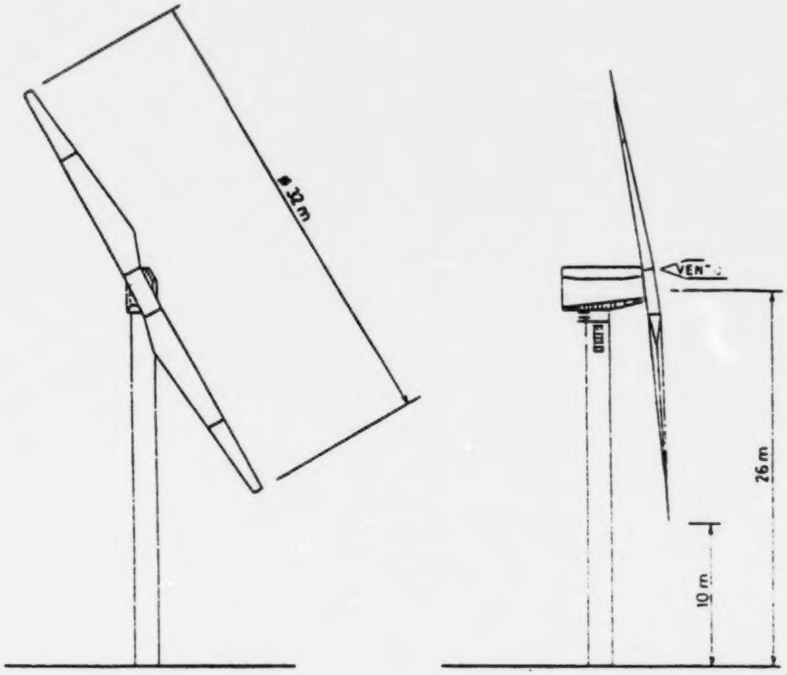
Multiblade pumping system

SEGEZIA - WENCO

Manufacturers or assemblers of wind energy systems TABLE A 1

small and medium-size

FIRM OR COMPANY	TECHNICAL DATA
AERITALIA - Via Archimede, 156 - Roma	Horizontal axis - two blades - Rated power 20 Kw - Grid connection or autonomous grid diameter 8,5 m - down wind - Cut in:4 m/s
BARDI E TOZZI Grosseto - Italy	Multiblade - Power 1 Kw - Water pumping
CAST - Via dei Tigli, 32 - 21014 Laveno M. (VA) Italy	Horizontal axis - 5 blades - water pumping or electrical power
CELOTTI ODILE (Treviso) 31020 Zoppé Italy	horizontal axis - three blades - diameter 5.1 m max power 8 Kw - horizontal axis - three blades diameter 6.4 m max power 15 Kw
DINAWATT - (SES) Vua Pontina Km. 22,500	Multiblade - water pumping Ø 4,6 or 6 m
EFEL- Via Scoffone 3/5 - 10095 Grugliasco Italy	Horizontal axis - three blades -rotor diameter 2,5 m - Power 0.75-1,5 Kw - Electrical power
FIAT AVIO - Corso Francia 112 - TORINO	Horizontal axis -three blades - 3 KW electrical power for small isolated users
RIVA CALZONI - Via Emilia Ponente, 72 -Bologna Italy	50 KW - Horizontal axis - grid connection Horizontal axis - single blade - upwind with orientation electrical servo-control-diameter 5.3 m - Rated wind speed 9 m/s - Rated power 3 Kw - max power 3.6 Kw - cut in 3 m/s -cut off 18 m/s - nominal speed 350 RPM -electrical power - Grid connection or autonomous grid
SALMINI - 21011 Casorate Sempione (VA) Italy	Horizontal axis - power 100 W - horizontal axis power 700 W - electrical power
SEI - Via San Iacopo, 34 -50047 Prato (FI)Italy	horizontal axis - three blades - two rotors - diameter 2,2 m - Rated wind speed 10 m/s - Rated power 1.5 Kw - cut-in 3 m/s - Electrical power (2 parallel rotors) - Horizontal axis - three blades - Rated power 0.75 Kw.
TDB -ViA Marconi 29/1 40122 Bologna Italy	Vertical axis - 3 KW



Tipo : Ad asse orizzontale, sopravvento

Rotore : Bipala, passo variabile tramite alette di estremità

Mozzo : Di tipo rigido

Regolatore : Unità logica programmabile

Moltiplicatore : Di tipo epicicloidale, rapporto 1 : 37,5

Generatore : Asincrono trifase, 4 poli, 200 kW, 400 V, 50 Hz

Sostegno : Tubolare metallico

Peso : ~ 22500 kg (escluso sostegno)

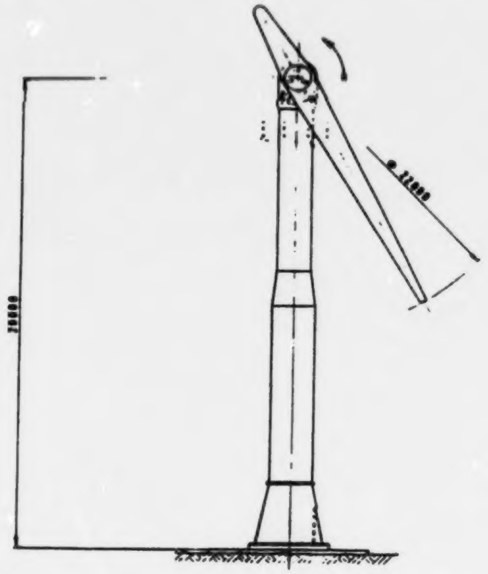
Diametro pale : 32 m

Altezza mozzo : 26 m

Velocità vento
- avviamento : ~ 4,7 m/s
- nominale : 11 m/s
- taglio : 20 m/s

Potenza nominale : 200 kW

- Aerogeneratore "Aeritalia", tipo AIT-02, da 200 kW MEDIT



GENERATORE EOLICO DA 200 kW MP 22

ROTORE

Numero di pale	1
Diametro	22 m
Velocità	variabile da 50 a 138,3 giri/min.
Direzione di rotazione	antiorario (vista sopra vento)
Posizione rispetto alla torre	Sopra vento
Tipo di mozzo	Oscillante
Regolazione di potenza	caratterist. programmata potenza/giri
Angolo di inclinazione	7°
Tip ratio	12
Area "spazzata" del rotore	380 m²
Dispositivo per arresto orizzontale della pala	

PALA

Lunghezza (Totale)	14,5 m -
Materiale	poliestere con fibre di vetro

TORRE

Tipo	tubolare rastremata ø 1800/1400
Materiale	acciaio
Clearance	9 m
Altezza	20 m
Fondamenta	cemento armato

MOLTIPLICATORE DI GIRI

Tipo	Epicicloidale a 2 stadi

GENERATORE

Quantità	1
Tipo	a corrente continua
Potenza nominale	200 kW
Tensione nominale	400 VCC
Velocità norm./max	2000/3000 giri/min
Ondulatore statico a controllo elettronico	Uscita 380 V trifase 50 Hz

COMANDO DI ORIENTAMENTO

Tipo	1 motore idraulico
Velocità di rotazione max della navicella	1,5 °/s

Freno a disco di manovra e di stazionamento su navicella

Messa in bandiera automatica (90° rispetto al vento) della navicella all'arresto

SISTEMA DI REGOLAZIONE

A giri variabili fino a velocità vento 13,3 m/sec.

A giri costanti con controllo elettronico della velocità di rotazione tramite freno magnetico per 13,3 < V < 20 m/sec

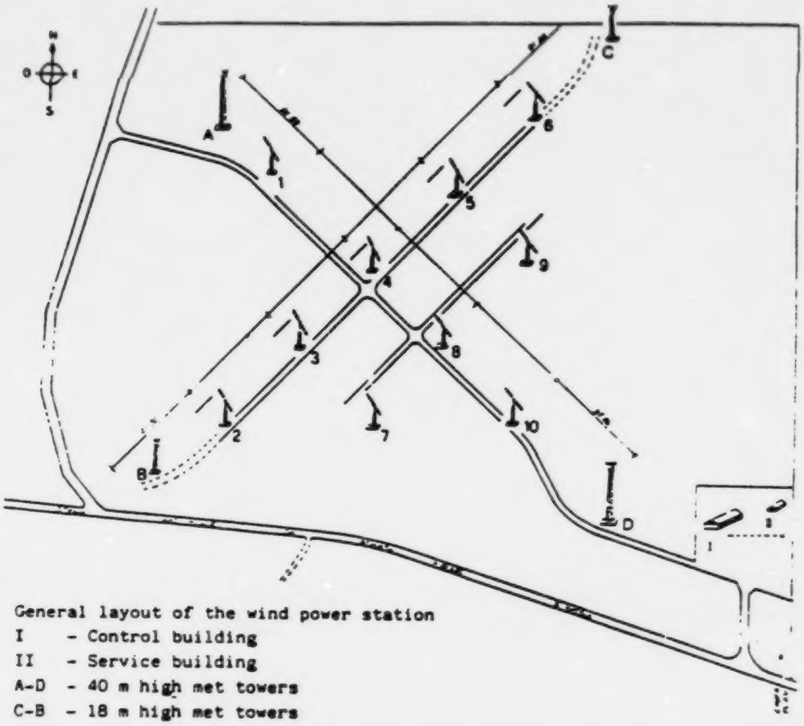
Anemometro direzionale per controllo imbardata

Sequenza automatica di avviam/arresto Allarmi e protezioni

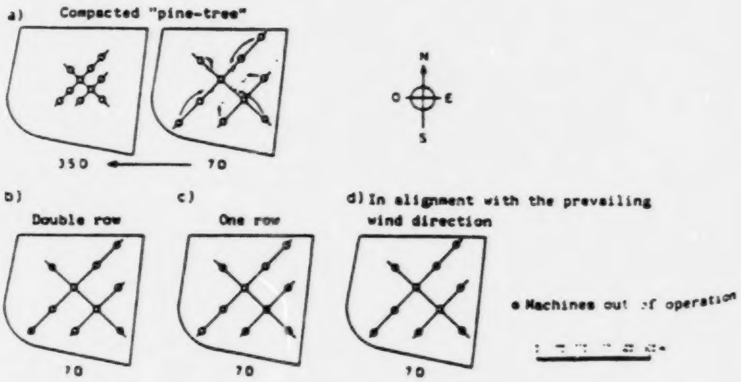
Protezione per sovravelocità tramite centrifuga meccanico-idraulica

PRESTAZIONI

Potenza nominale all'asse elica	240 kW
Potenza nominale elettrica	200 kW
Velocità del vento	
Partenza	5,5 m/s
Nominale	13,3 m/s
Arresto	2[illegible] /s


N
O
E
S
A
B
C
D
1
2
3
4
5
6
7
8
9
10
I
II

General layout of the wind power station
I - Control building
II - Service building
A-D - 40 m high met towers
C-B - 18 m high met towers
1-10 - Wind-turbine generators


a) Compacted "pine-tree"
350
70
N
O
E
S
b) Double row
c) One row
d) In alignment with the prevailing wind direction
70
70
70
● Machines out of operation

Wind-turbine clusters obtainable with the "pine-tree" array

- "Alta Nurra" 500 kW wind power station

Type : Horizontal axis, with downwind rotor

Rotor : Two blades, with variable pitch and feathering

Hub : Teetering

Control system : Hydro-mechanical, with start-up and shut down remote control

Transmission : Two stage co-axial gearbox, ratio 1 : 15.2

Generator : Three-phase asynchronous generator, 4 poles, 55 kW, 400 V, 50 Hz

Tower : Cylindrical steel shell

Total weight : ~2200 kg (above tower)

Rotor diameter : 13.5 m

Hub height : 18.5 m

Wind speed (at hub height)

- cut-in : ~5 m/s
- rated : 11.3 m/s
- cut-out : 30 m/s

Rated power : 50 kW

- "ENEL-FIAT" 50 kW wind-turbine generators set up at the "Alta Nurra" wind power station

LIBELLULA WIND GENERATOR, 3KW BY FIAT

SEGEZIA WIND GENERATOR BY WENCO

SEGEZIA VERTICAL AXIS WECS

ACTIVITIES ON CWD-TESTFIELDS DURING '84/'85

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ABSTRACT

The CWD has three testfields in operation in The Netherlands: in Eindhoven, Almere and Vriezenveen, where in total 10 water pumping windmills are being tested.
Performance measurements (of output and safety system functioning) as well as short term measurements (of peak rotating speeds, starting and stopping wind speeds) are being carried out.
Some performance measurements on the CWD 2000 are treated in this paper, as well as how tests are reported by CWD.
Field tests on wind measuring systems are reported.

INTRODUCTION

CWD (Consultancy Services Wind Energy Developing Countries) is an organization initialized and funded by the Netherlands' Ministry of Development Cooperation. It aims to help governments, institutes and private parties in the Third World in their efforts to use wind energy and in general to promote the interest for wind energy in developing countries. The emphasis of the activities of CWD is on water pumping windmills, coupled to single acting piston pumps.
Participants of CWD are:

- DHV Consulting Engineers, Amersfoort
- Eindhoven University of Technology (Wind Energy Group)
- Twente University of Technology (Windmill Group)
- ILRI (Institute of Land Reclamation and Improvement), Wageningen.

CWD-designed water pumpers are in operation in Sri Lanka, Pakistan, Tanzania, Mozambique, Mauretania, Tunesia, Peru, Cape Verde and Ghana. Implementation projects are being carried out in Cape Verde and Sri Lanka, and are in preparation for Sudan, Kenya, Nicaragua, Somalia and Mozambique. Developement of prototypes is mainly done in The Netherlands.
For field testing of water pumping windmills, CWD has testfields in Eindhoven, Vriezenveen (close to Twente University) and Almere (in one of the polders in the former Zuiderzee).
This paper deals with the activities and general results of these 3 test-fields. Special short term measurements which are aimed to investigate the starting and stopping phenomena of water pumping windmills will be reported in a separate paper, also to be presented at this conference.

SURVEY OF WORK DONE

The following type of tests are of importance when testing water pumping windmills:

- functional tests;
- measurements: output performance, behaviour of safety systems, peak rotational speeds.

The monitoring system (sensors, data collection and elaboration) in use on CWD testfields was developed by the Wind Energy Group in Eindhoven (ref. 1, 2, 3). The system is also in use at the autonomous wind-diesel electricity generating system at ECN (Energy Research Foundation Netherlands) in Petten. Moreover, it was used to monitor the performance of the Wind electric pumping system (a windgenerator driving an electrical submersible pump in a tubewell), of which the first prototype is now in operation on the Cape Verdian Islands.

The three CWD testfields have different vocations:

a) The Almere test field (which has a very good wind regime) is meant for functional tests, output performance measurements and endurance tests (to know the maintenance and repair requirements); only fully developed windmills are tested there.
The Almere testfield became operational in November 1984. DHV Consulting Engineers is in charge of the testfield operation. At the moment three commercially available windpumps are being tested:

- 2 m Ø OASIS (manufactured in France)
- 3 m Ø FIASA (Argentina; it is identical to Aermotor)
- 17' Ø SOUTHERN CROSS (Australia).

No test reports are avialable, yet.

b) The Vriezenveen testfield is meant for functional tests and output performance measurements on prototypes developed by the Windmill Group of THT. The CWD 5000 (the number refers to the rotor diameter in mm) has been tested there in two versions:

- one with a deepwell pump
- one with a low lift/high volume pump.

The test results revealed that the peak rotational and yawing speeds were too high; this led to an important modification in the safety system. The CWD 8000 will be tested in the second half of 1985.

c) The Eindhoven testfield (figure 1) is meant for:

- functional testing of prototypes
- performance testing of prototypes
- special measurements (like short term measurements, measurements of of stresses and forces)
- development and testing of monitoring systems
- anemometer tests.

During '84/'85, the following prototypes have been tested in Eindhoven:

- CWD 2000 (fig. 2): being tested; some results reported in Ref. 2, 4 and 5.

- CWD 2740: being tested; some results reported in Ref. 2.
- CWD 5001: being tested.
- WEU-I/3 (a 3 m Ø prototype designed by the Wind Energy Unit in Sri Lanka in collaboration with CWD). Measurements on the WEU-I/3 were completed (Ref. 4, 5) and the mill was dismantled in April '85. The measurements have led to the conclusion that for the design of the fourth generation windmill, the WEU-I/4, a new safety mechanism has to be conceived.
- CWD 5000 HW: tests were completed and reported in Ref. 1. The prototype remains at the testfield for field testing of pumps and pump appurtenances.

Short term measurements have been performed on the CWD 2740 (Ref. 7), which will be treated in a separate paper, also to be presented at this conference. Measurements of pumprod forces in field conditions are in preparation.
A large number of performance measurements have been carried out on the CWD 2000 with different starting devices applied to the pump. These will be briefly reported hereunder. Six commercially available wind measuring systems have been tested both in the windtunnel and on the testfield (Ref. 8 and 9). The results will be mentioned at the last section of this paper.

REPORTING

The results of testfield activities of CWD are reported in four types of reports:
a) reports on functional tests (like Ref. 6);
b) reports on field measurements (Ref. 4, 5);
c) reports on special measurements (Ref. 7, 9);
d) analysis reports, in which theory and results of laboratory and field measurementss are compared with each other and conclusions are drawn.

It is attempted to standardize the reports of types a) and b) as far as possible.
The reports on field measurements, for instance, contain:
- lay-out of the testfield;
- description of the measurements (i.e. sensors, data collection);
- description of the software used;
- test circumstances (i.e. location, test configuration, suction and pressure heads, pump diameter and stroke, etc.);
- elaboration of the data:
  - in time sequence
  - in bin sort (table and graphs);
- conclusions.

Presentation in time sequence has proven to be extremely useful to check the correct functioning of the sensors. An example of time sequenced presentation is given in Figure 3 (taken from Ref. 4).
An example of bin sort presentation is given in Figure 4 (taken from Ref. 4).
Ref. 10 can be regarded as an example of an analysis report;

Field measurements on the CWD 5000 (Vriezenveen) were analyzed and compared with those of a Dempster 8' (measurements done by the Renewable Energy Division of the Ministry of Rural Development, Republic of Cape Verde). The first step of the comparison is to relate the measurements to their respective design wind speeds (see Fig. 5; taken from Ref. 10). The comparison itself can only be made after multiplication with a windspeed distribution, for example the Rayleigh distribution. This leads to presentations like Figure 6, in which output and availability (fraction of time that the windmill is actually pumping) are given as a function of the ratio of design windspeed and average windspeed. Presented in this way, the results of field tests are useful and comprehensible not only for the designer, but also for the user.

MEASUREMENTS ON CWD 2000

CWD prototypes have a small hole in the piston of the pump to reduce the starting torque. The design formula of the starting hole diameter is based on a 10% loss of output at the design windspeed.
From field measurements at the CWD 2000 it appeared that this design rule is not adequate, at least not for such a small windmill; apparently the kinetic energy stored in the rotor when it runs its first strokes, has to be taken into account. Waterdelivery, then, is not just a function of rotational speed.
To prove this, CWD technicians developed a piston valve which remains open at starting (so no water lifted) and closes at a certain rotor speed (cut-in speed). Closing of the valve is electronically triggered. Results of both types of starting devices are compared with each other in Figure 7. The cut-in rotational speed that resulted in the highest power coefficient of the electronically regulated valve was experimentally determined by measuring the power coefficient curve with the automatic data acquisition system. Each series took just a couple of days.
Figure 7 clearly shows that a piston valve which closes at a certain rotational speed, gives far better results than a starting hole.
The electronically regulated valve, however, is not a practical solution, since in field conditions in developing countries, no power supply is available. Experiments are now underway, to obtain the same result with a large volume/low weight piston valve, where the closing is governed by its buoyancy and inertia.

ANEMOMETER TESTING

Six wind measuring systems have been tested in Eindhoven (Ref. 8, 9). They are:

- for simple wind run measurments:
  1. National Power wind data accumulator A22
  2. Aeolian Kinetics wind prospector WP 4000;
- for rough site analysis (measurement of distributions):
  3. Theodor Friedrichs wind analyzer
  4. Lagerweij Van de Loenhorst LK 6801;
- for wind surveys (time sequential data storage):
  5. Aeolian Kinetics datalogger MS 778
  6. Helion wind prospector model 80.

The first striking remark to be made is that systems 2, 4 and 5 are not manufactured anymore! The above systems were chosen after a market survey done in 1982.
The general conclusion of Ref. 9 is repeated here: "Altogether it turned out that the main problems occurred with the more advanced wind measuring systems. A lot of attention should be paid to the power supply of these systems, because failing power source is the cause of many problems.
For simple wind run measurements the Natural Power A22 can be recommended and for somewhat more detailed measurements the Theodor Friedrichs offers good opportunities."

All anemometers were also tested in the windtunnel. From the conclusions of the test report (Ref. 8): "Calibrations presented by manufacturers assume that the calibration-line (frequency versus windspeed) passes the origin. This appears to be uncorrect and is the main reason why most anemometers do not fulfil the IEA-nor WMO-standards. After a simple correction (add e.g. 0.5 m/s to all measurements), the anemometers do fulfil the standards.
The dynamic behaviour was investigated by determining the distance-constant of each anemometer. This constant should be lower than 5 m. The Maximum anemometers do fulfil this standard, while heavier types like Lambrecht and Casella, do not.

ACKNOWLEDGEMENT

Several CWD staff members are involved in the activities at the three test fields. The creativity and dedication of Henk Oldenkamp and An van der Nat of the Wind Energy Group in Eindhoven should be mentioned in particular. Besides CWD staff, students of both Eindhoven and Twente University have contributed as well.

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10. Niko Pieterse, Joop van Meel, Paul Smulders, Comparison of output and availability of a CWD prototype and an American multibladed water pumping windmill based on field measurements, to be published in RERIC's Renewable Energy Review Journal, December 1985.

FIGURES

1. Photo of Eindhoven test field.

2. Photo of CWD 2000 at Eindhoven test field.

3. Example of time sequenced presentation of data (page 14 of Ref. 4).

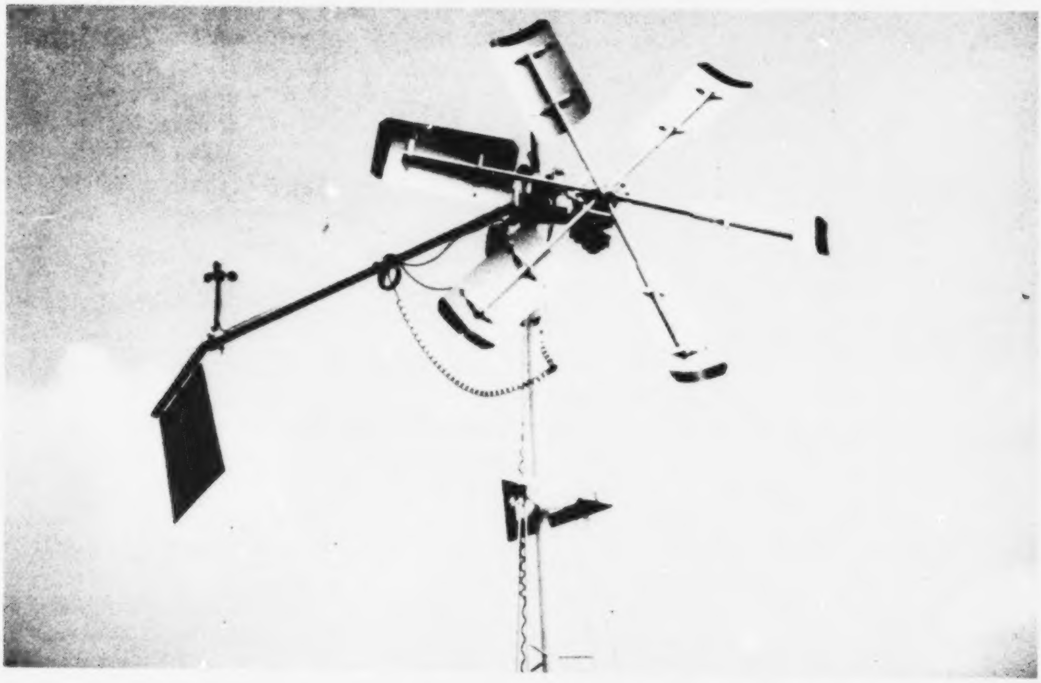
4. Example of bin-sort presentation of data (page 23 of Ref. 4).

5. Overall power coefficient curves (field measured and calculated from windtunnel and pump test stand measurements) of CWD 5000, Vriezenveen, the Netherlands (Figure taken from Ref. 10).

6. Quality factor and availability of CWD 5000 and Dempster 8' as a function of $Vd/\overline{V}$ (Figure taken from Ref. 10).

7. Overall power coefficient curves of the CWD 2000:
   a) without starting device
   b) with starting hole
   c) with electronically regulated valve.

Figures 1 and 2



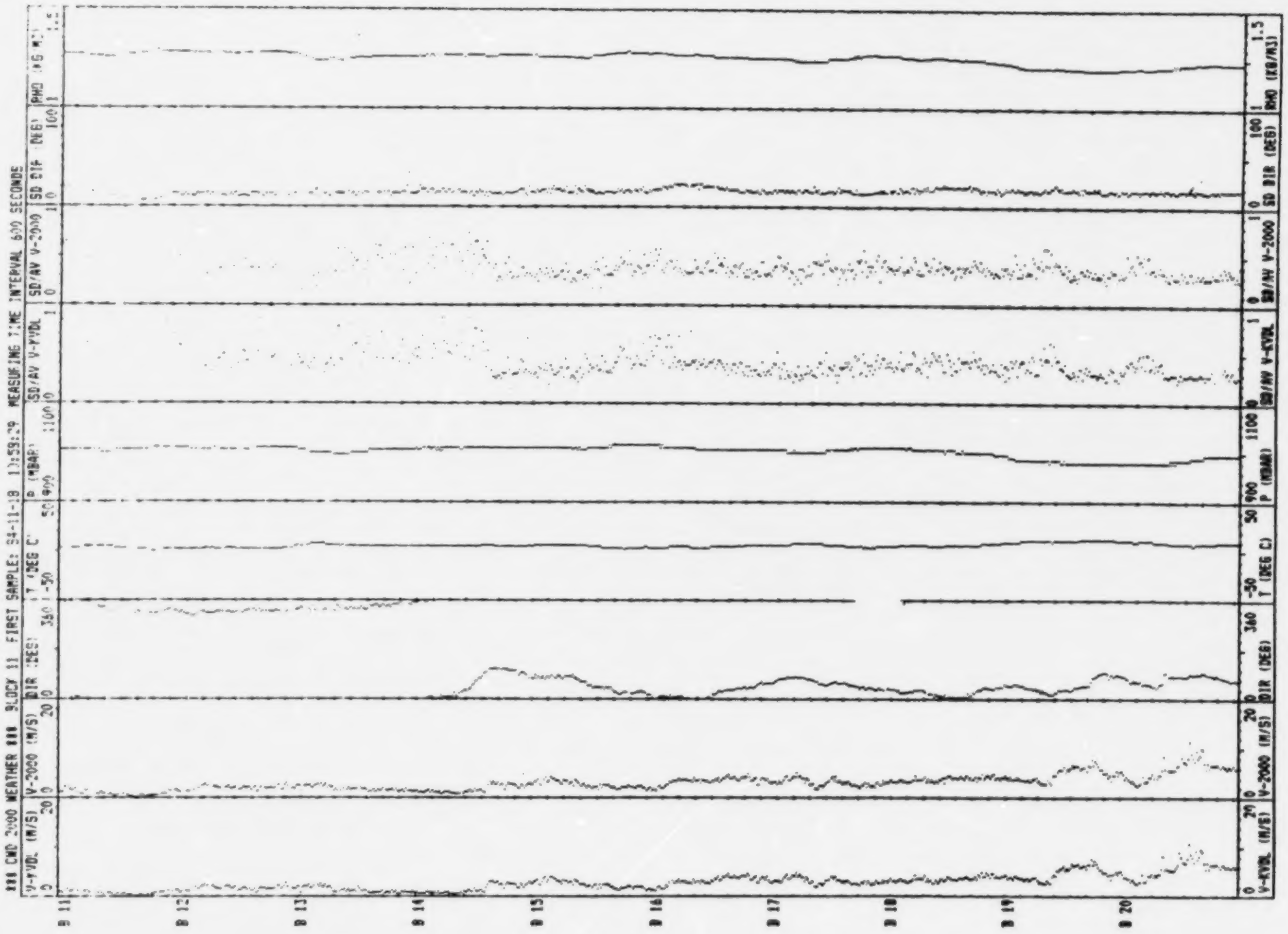
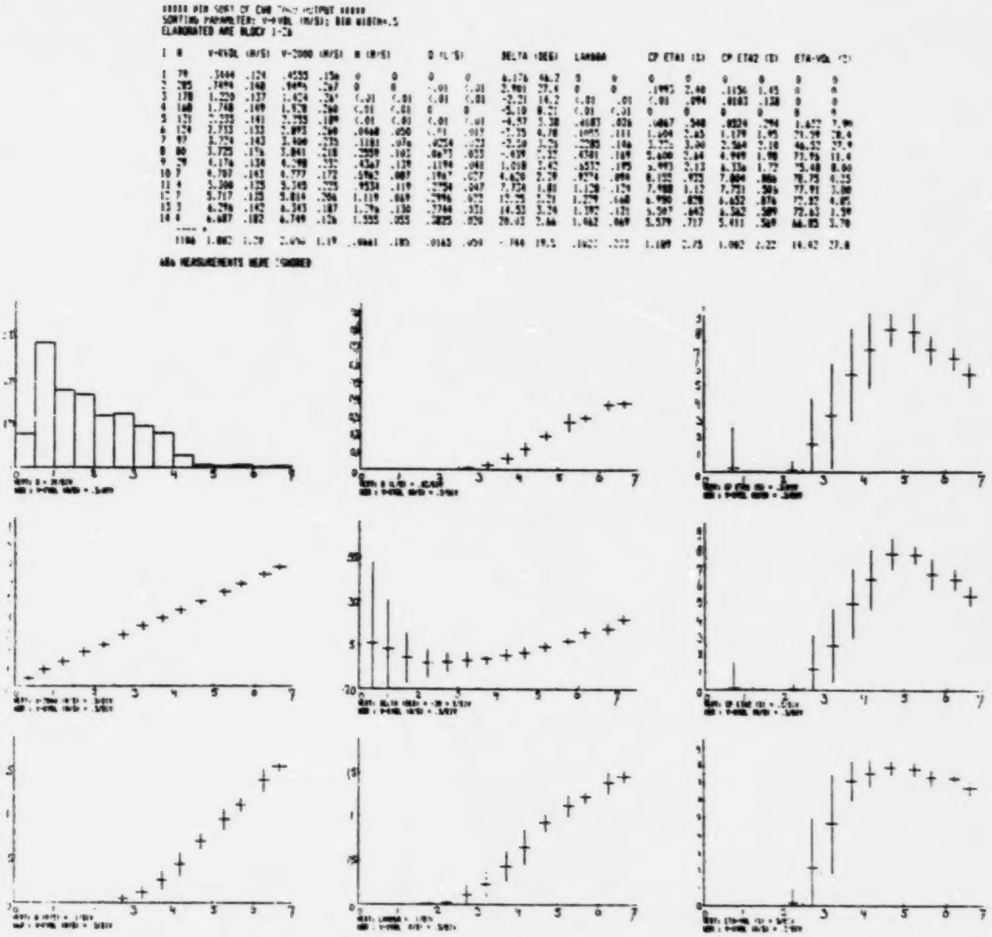


Fig.3. PLOT DATA output of data disk 16, block 11-20 using the 'formulas CWD 2000 weather' program.

During these blocks the barometer drops about 40 mBar and the wind speed increases until about 10 m/s.



```
SORTING PARAMETER: V-KVDL (M/S); BIN WIDTH=.5
ELABORATED ARE BLOCK 1-26

I  N   V-KVDL (M/S)  V-2000 (M/S)  W (M/S)   Q (L/S)   DELTA (DEG)  LAMBDA   CP ETA1 (%)  CP ETA2 (%)  ETA-VOL (%)

486 MEASUREMENTS WERE IGNORED
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Fig.4. Bin sort output of data disk 16, using 'formulas CWD 2000 output' with V-kvdl as bis sort parameter, selecting wind directions between SSW and WWN.

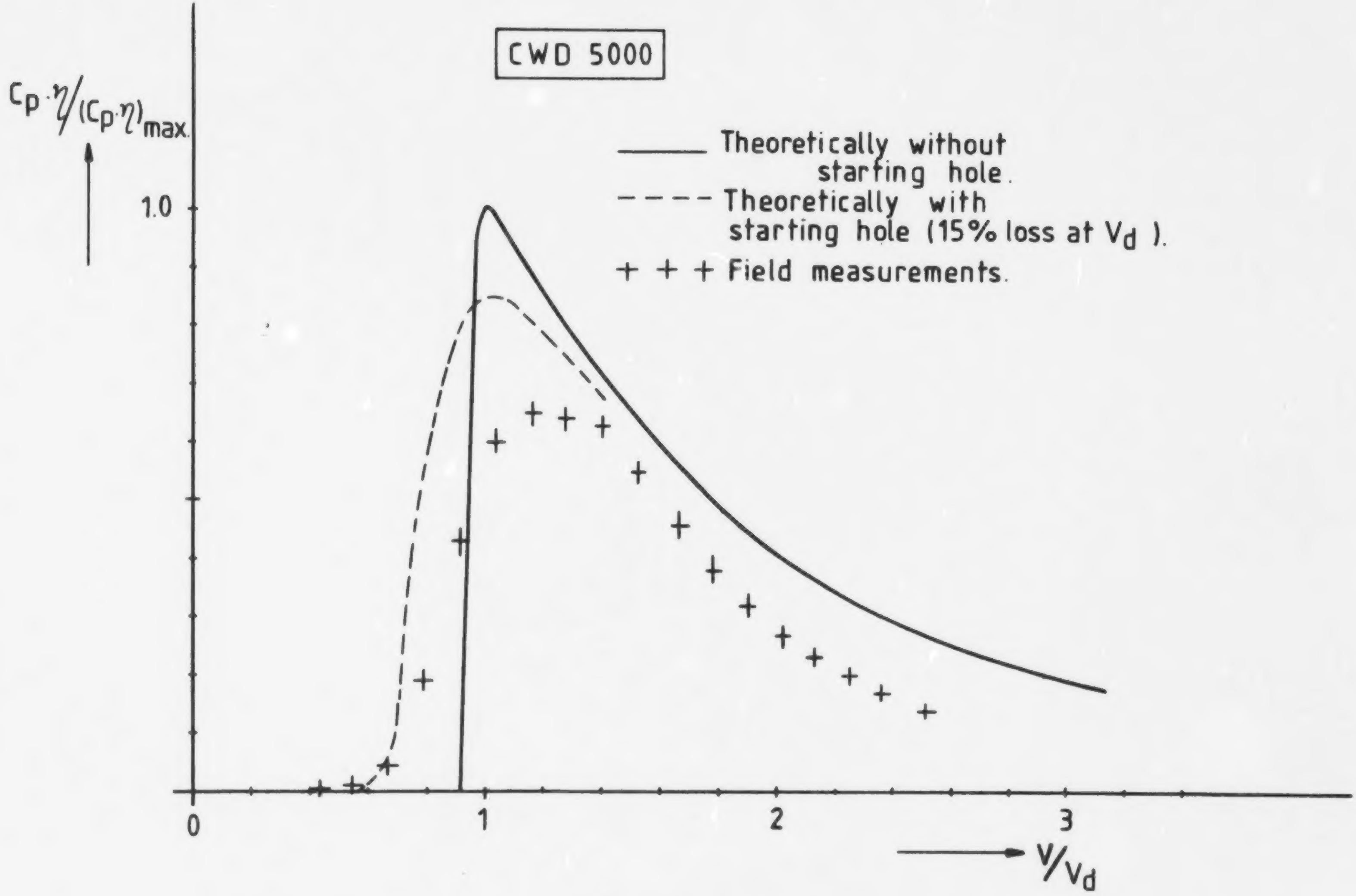

Figure 5. Overall power coefficient curves (field measured and calculated from windtunnel and pump test stand measurements) of CWD 5000.

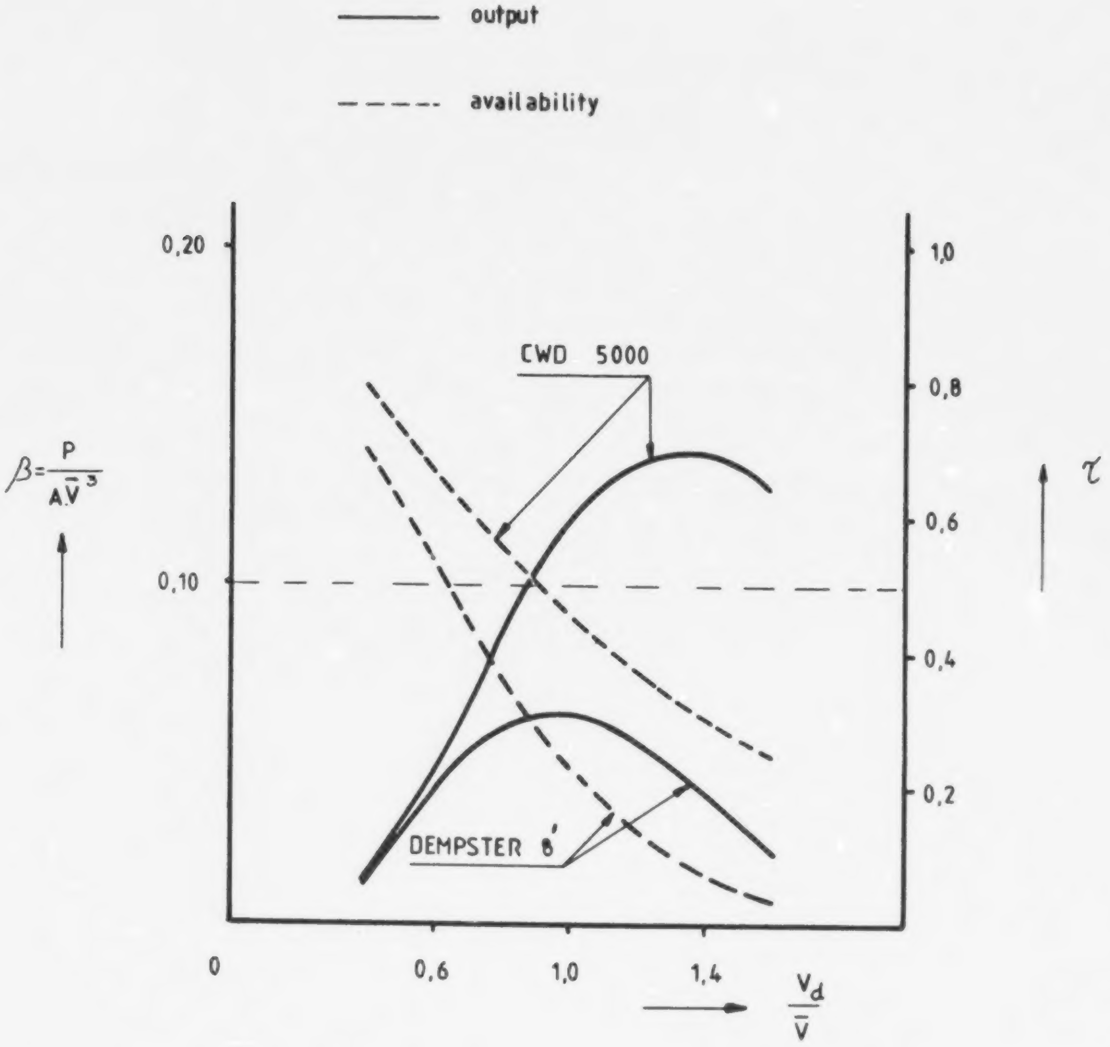

Figure 6. Quality factor and availability of CWD 5000 and Dempster 8'.

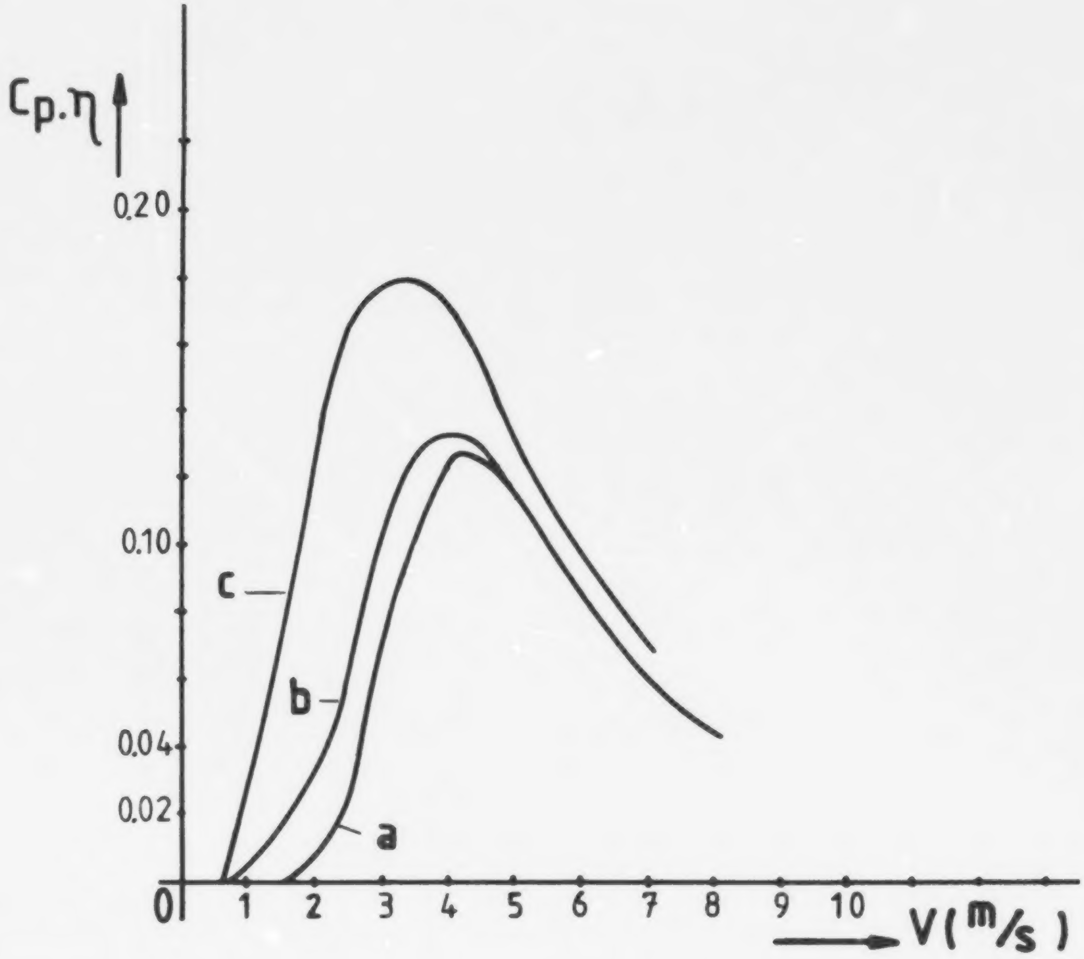

Figure 7. Overall power coefficient curves of the CWD 2000:

a) without starting device

b) with starting hole

c) with electronically regulated valve.

**CONSULTANCY SERVICES
WIND ENERGY
DEVELOPING COUNTRIES**

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3800 AB AMERSFOORT
THE NETHERLANDS

TECHNICAL SPECIFICATIONS WIND PUMP MODELS CWD 2000, CWD 2740 AND CWD 5000 LW.

CWD has developed a number of standard wind pump models and special versions to suit various purposes. The design proces is determined by CWD's aim to enable local production in developing countries. This has lead to following main design criteria:
- a service life of 10 years
- the use of locally available materials
- the use of elementary construction techniques and equipment
- easy maintenance and servicing.

The designs enable a decentralized production of windmills, while servicing may largely be done by the users themselves.

The standard CWD wind pump models are the CWD 2000, the CWD 2740 and the CWD 5000 LW.
For these wind pumps CWD designed four types of single acting piston pumps with cylinder diameters of 65, 100, 150 and 250 mm.

The Sri Lanka version of the CWD 2000.

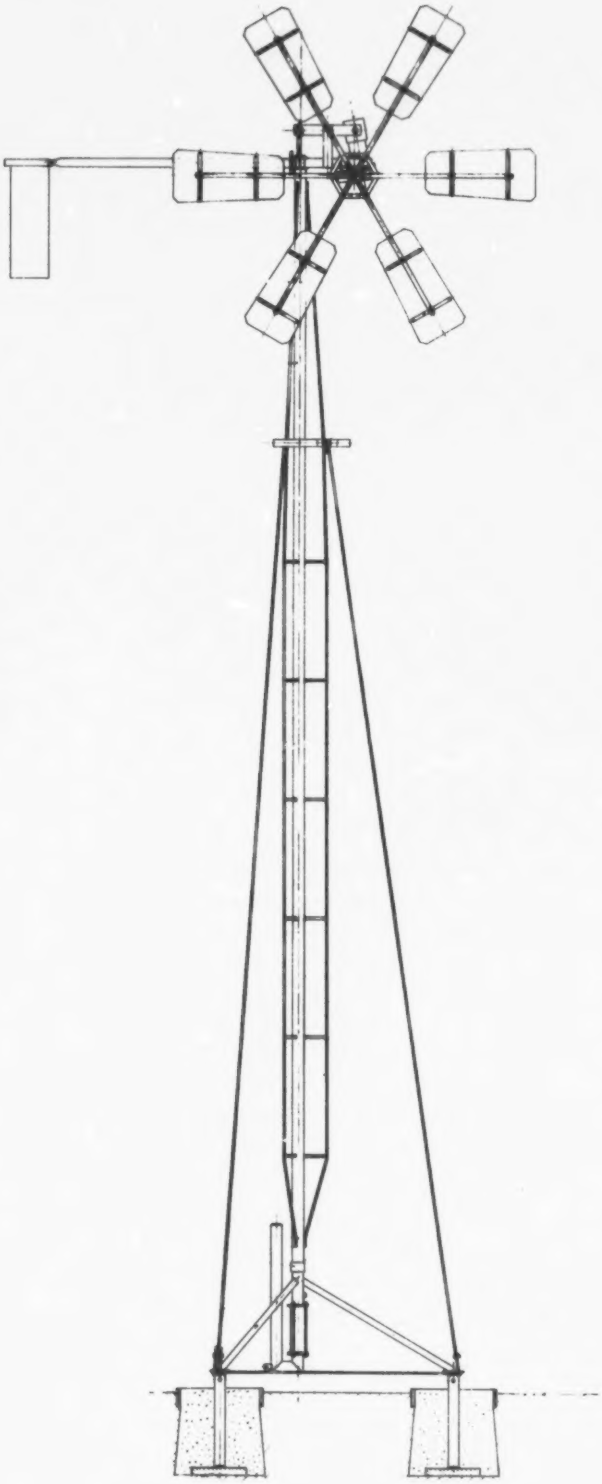
The Peru version of the CWD 2740.

The stroke is adjustable. The pumps may be situated under water or above ground level, depending on the type of water source and the water level.

Possible combinations:

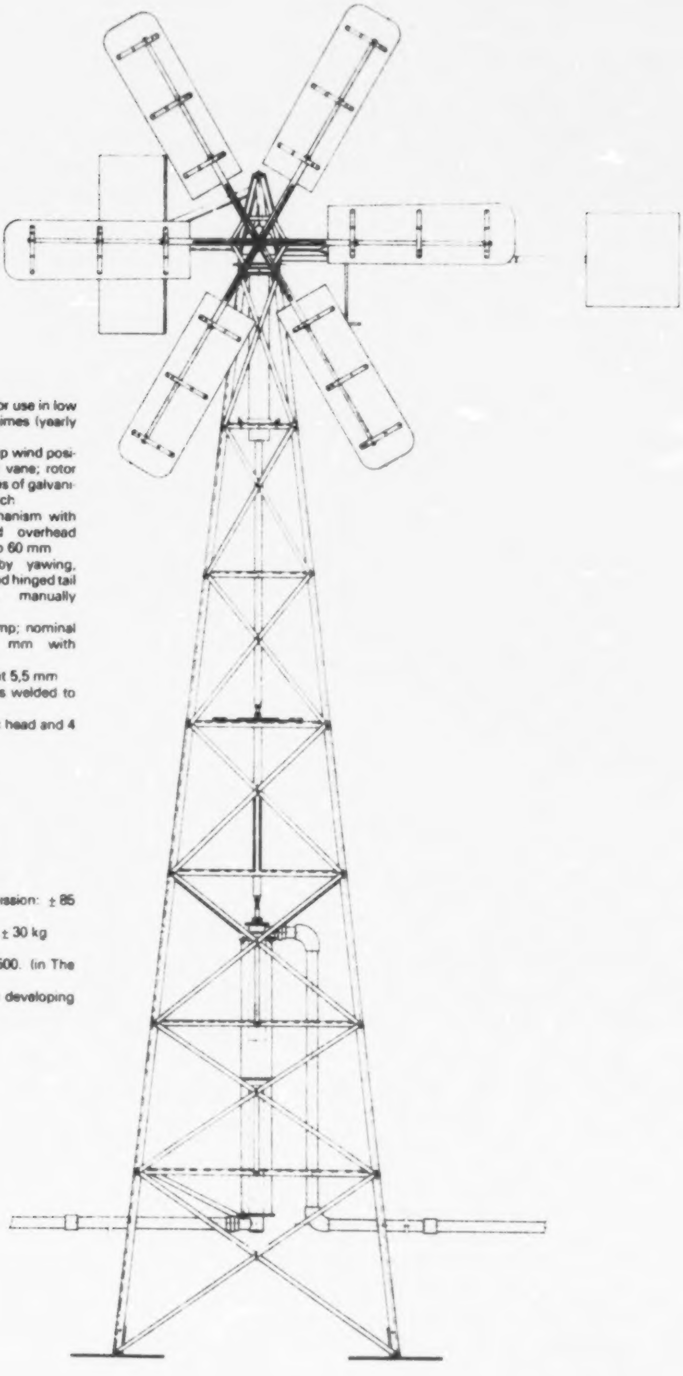
Wind pump	Rotor diameter (mm)	Pump diameter (mm)	Stroke (mm)	Head (m)
CWD 2000	2000	65 / 100	25- 60	2- 12
CWD 2740	2740	65 / 100 / 150	25-100	2- 20
CWD 5000 LW	5000	100 / 150 / 250	80-200	2-100

The next pages show the specifications of a special version of each standard CWD wind pump model.



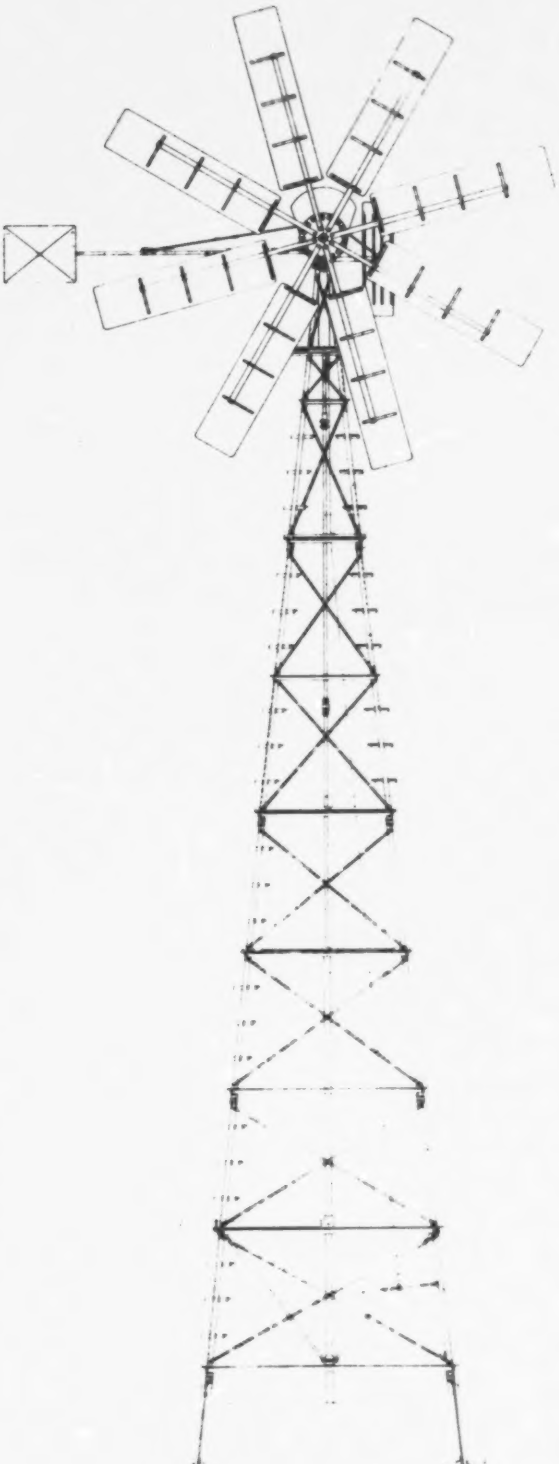
CWD 2000

PURPOSE	water lifting; designed for use in low and moderate wind regimes (yearly averages below 5 m/s)
ROTOR	horizontal axis; kept in up wind position by balance of side vane and excentric rotor; rotor diameter 2 m; 6 blades of galvanized steel sheet; fixed pitch
TRANSMISSION	direct drive crank mechanism with adjustable stroke and swing arm; strokes 25-100 mm; balanced pump rod weight
CONTROL SYSTEMS	over speed control by yawing, activated by exentric rotor and hinged side vane system
PUMP SYSTEM	single acting piston pump with starting nozzle and air chambers; nominal pump diameter 65 mm
TOWER	steel tubular mast; height 6.5 m; can be lowered by means of hinges in the tower base
CAPACITY	25 m³/day at 5 m static head and 3.5 m/s average wind speed.
OPERATING WIND SPEEDS	-cut-in : 2.5 m/s -rated : 6 m/s -survival: 40 m/s
AERODYNAMIC PROPERTIES	-λ (design): 1.5 -Cp (max): 0.3 -solidity: 0.35 -typical design wind speed: 3 m/s
WEIGHTS	total (excl. foundation): ± 150 kg
COST	materials ± US $ 150.- (in The Netherlands)
STATUS	one is operating in The Netherlands since April 1983 and another one in Sri Lanka since June 1983



CWD 2740

PURPOSE	: water lifting: designed for use in low and moderate wind regimes (yearly averages below 6 m/s)
ROTOR	: horizontal axis; kept in up wind position by means of a tail vane; rotor diameter 2.74 m, 6 blades of galvanized steel sheet; fixed pitch
TRANSMISSION	: direct drive crank mechanism with adjustable stroke and overhead swing arm; strokes up to 60 mm
CONTROL SYSTEMS	: over speed control by yawing, activated by side vane and hinged tail vane system; with manually activated furling device
PUMP SYSTEM	: single acting piston pump; nominal pump diameter 150 mm with air chambers
TOWER	: lattice steel tower; height 5,5 mm
FOUNDATION	: earth loaded steel plates welded to tower legs
CAPACITY	: 35 m³/day at 10 m static head and 4 m/s wind speed.
OPERATING WIND SPEEDS	: - cut-in : 3 m/s - rated : 8 m/s - cut-out : 12 m/s - survival: 40 m/s
AERODYNAMIC PROPERTIES	: - λ (design): 2 - Cp (max): 0.38 - solidity: 0.34 - typical design wind speed: 3 m/s
WEIGHTS	: - rotor, head and transmission: ± 85 kg; - pump, with pump rod: ± 30 kg - tower: ± 155 kg
COST	: materials only ± US $ 500. (in The Netherlands)
STATUS	: 10 systems operating in developing countries



CWD 5000 LW

PURPOSE	: water lifting; designed for use in low and moderate wind regimes (yearly averages below 6 m/s)
ROTOR	: horizontal axis; upwind position by means of a tail vane; rotor diameter 5 m, 8 blades of galvanized steel sheet; fixed pitch
TRANSMISSION	: direct drive crank mechanism with adjustable stroke and overhead swing arm; strokes: 80-200 mm
CONTROL SYSTEMS	: over speed control by yawing, activated by side vane and hinged tail vane system; with manually activated furling device
PUMP SYSTEM	: single acting piston pump with pressure air chamber and starting nozzle; galvanized steel pump; nominal pump diameter of 150 mm.
TOWER	: lattice steel tower; height 12 m (alternative 9 m)
FOUNDATION	: requires about 1 m³ reinforced concrete per leg.
CAPACITY	: 50 m³/day at 20 m static head and 4.5 m/s wind speed.
OPERATING WIND SPEEDS	: -cut-in : 4 m/s -rated : 9 m/s -cut-out : 12 m/s (automatic furling between 8 and 12 m/s) -survival: 50 m/s
AERODYNAMIC PROPERTIES	: -λ (design): 2 -Cp (max): 0.35 -solidity: 0.34 -typical design wind speed: 4.5 m/s
WEIGHTS	: -rotor, head and transmission: ± 350 kg; -tower: 450 kg (9 m) resp. 650 kg (12 m) -pump including 25 m piping below ground level 280 kg
COST	: materials only ± US $ 1000.- (in The Netherlands)
STATUS	: one system in The Netherlands operating since December 1982.

CONSULTANCY SERVICES
WIND ENERGY
DEVELOPING COUNTRIES

P.O. BOX 85
3800 AB AMERSFOORT
THE NETHERLANDS

A brief introduction to the Netherlands program for assistance to developing countries in the utilization of wind energy.

Februari 1984

The basis for a sound economic development of many countries in the Third World is the development of agriculture The oil crisis in 1973 once again stressed the vital role of energy in this development process and thus caused a world-wide revival of the interest in the utilization of renewable energy sources. In the Netherlands wind energy still appeals to many people and in 1974 a study was made to analyse the possibilities of utilizing wind energy in developing countries. It appeared that in many countries wind energy could play an important role in satisfying the energy need for water pumping, particularly for irrigation purposes.

In 1975 the Netherlands government founded a national organization in order to coordinate the Netherlands activities on wind energy for developing countries.
This organization operated under the name Steering Committee Wind Energy Developing Countries until 1984. In that year the name of the organization was changed into CWD Consultancy Services Wind Energy Developing Countries.
CWD promotes the interest for wind energy in developing countries and aims to help governments, institutions and private parties in the Third World with their efforts to utilize wind energy.

The CWD pursues this aim in three ways

1. provision of assistance to wind energy projects in developing countries
2. wind energy research, mainly undertaken in the Netherlands
3. transfer of knowledge on wind energy use.

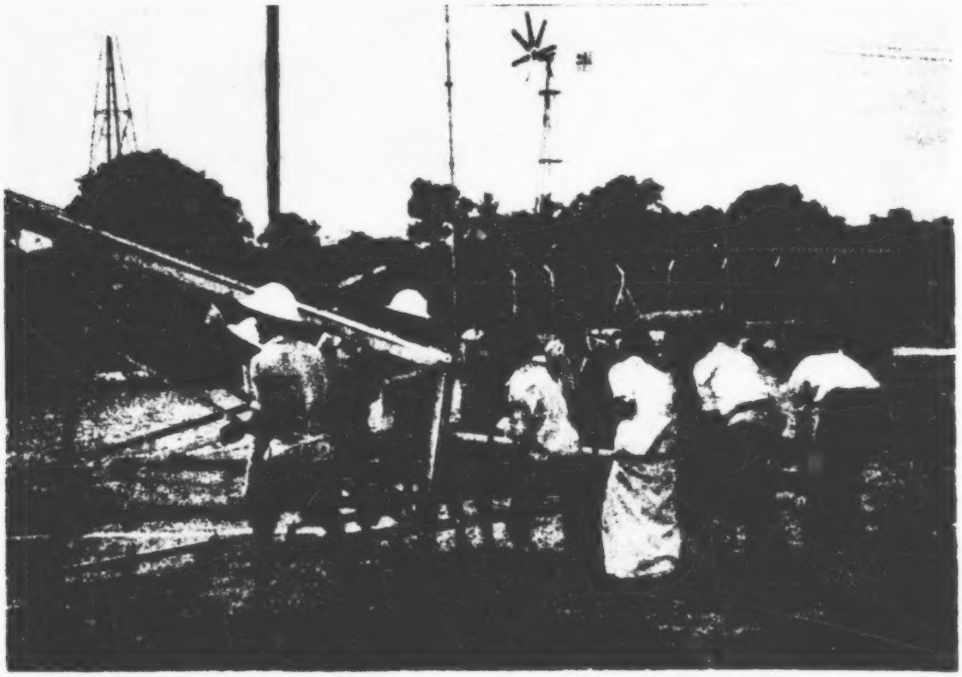
The parties that currently participate in CWD are

Eindhoven University of Technology (Wind Energy Group)
Twente University of Technology (Windmill Group)
DHV Consulting Engineers.

Each participant has its own, more or less well defined, field of research and the co-ordination is in the hands of DHV Consulting Engineers.

In the field of agriculture CWD closely collaborates with the Institute of Land Reclamation and Improvement (ILRI).

CWD has regular contacts with the Working Group on Development Technology (WOT) at Twente University.
Also contacts exist with the Dutch national wind energy research program, co-ordinated by the Energy Research Centre (ECN).



The installation of a ∅ 5 m windmill in Colombo, Sri Lanka; in the background the ∅ 3 m WEU-I windmill.

RESEARCH ACTIVITIES

The research activities are undertaken with the following purposes:
- to develop windmill components as well as complete prototypes
- to support the country projects
- to train future experts for country projects

Rotors

A large number of rotors have been designed and tested, both at open air test stands and in a large windtunnel. Good results have been achieved with horizontal axis curved metal plate rotors, as predicted by theory. For low Reynolds numbers (< 100,000) curved plate profiles turn out to be better than airfoils.
Designing with higher tip speed ratios ($\lambda > 1$) results in lighter rotors and thus lighter and cheaper windmills.

Pumps

The optimum matching of a pump to the quadratic torque-speed characteristic of a wind rotor has been pursued by the development of variable torque reciprocating pumps and the application of centrifugal pumps. This optimum matching results in much higher overall outputs than with the traditional (constant torque) piston pumps. The closing of valves and the operation of air chambers has been analyzed.

Generators

For deep wells electrically driven pumps are considered as a serious alternative to direct mechanically driven pumps. Two types of generators have been tested to drive these pumps:
- a self exciting induction generator
- an induction generator equipped with a permanent magnet rotor

Also two control systems for alternators have been developed.
Research is done on autonomous systems, windmills for electricity generation working in combination with diesel powered generators.

Safety Systems

A reliable safety system has been developed and tested for wind speeds up to 30 m/s. The system operates by means of a small auxiliary vane that pushes the rotor out of the wind against the normal directional vane that is hinged on a leaning axis. A complete theoretical model is being studied.

Wind measurement

An electric counter with extremely low energy consumption has been developed for contact-anemometers.

Theory

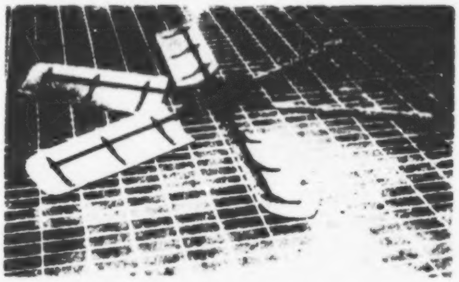
Theoretical models have been developed or refined on:
- rotor performance
- forces on rotor blades
- output in different wind regimes
- matching of rotor with generator or pump
- dynamic behaviour of pumps.

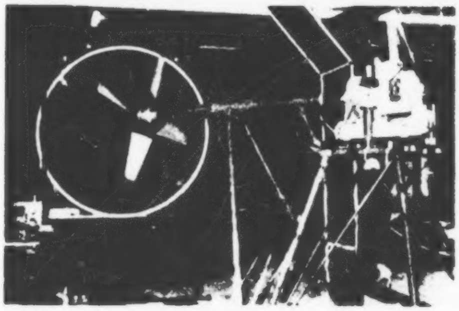
Windmill prototypes

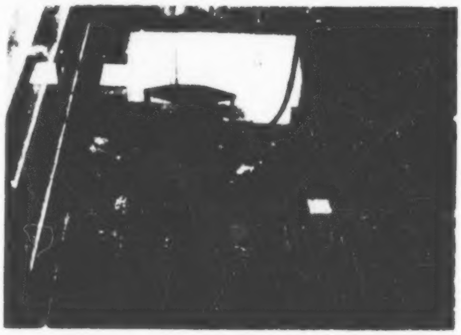
The following prototypes have been developed:

	diameter	number of blades	tip speed ratio	remarks
CWD 2740	2.74 m	6	2	piston pump
CWD 4000	4.00 m	8	2	piston pump
CWD 5000 RS[1]	5.00 m	4	5	centrifugal pump, Rotating Shaft
WEU I	3.00 m	6	2	piston pump
WEU II[2]	5.00 m	8	2	piston pump
Cretan	6.00 m	8	1	piston pump
Under development				
CWD 5000 HW	5.00 m	8	2	piston pump: for High Wind regime
CWD 5000 LW	5.00 m	8	2	piston pump. for Low Wind regime
CWD 2000	2.00 m	6	2	piston pump
CWD 1000 EL	1.00 m	2	4	Electricity generation

[1] developed as testmodel only
[2] partially based on WOT designed 12 PU 500
[3] developed by WOT with financial aid from CWD


Rotor of CWD 2740 prototype


Windtunnel (Ø 2.2 m) at Delft University of Technology for testing rotor models


Pump test stand at Eindhoven University of Technology

Project for rural water supply and irrigation on the Cape Verdian Islands

Prototype installed in Hammamet, Tunisia, irrigating an orchard

COUNTRY PROJECTS

CWD gives assistance in the execution of wind energy programmes in close co-operation with interested ministries, institutions or private parties. The country projects encompass assistance in a number of fields.
— measurement and analysis of wind data
— selection of favourable areas
— selection and construction of prototype windmills
— training and education in the field of wind energy
— selection of application purposes
— organisation of pilot projects.
— maintenance
— agricultural application analysis
— production engineering assistance
— economic programming and
— credit systems

The guiding principles for the country projects are.
— water pumping has the highest priority
— local production of as many components as possible
— construction methods and materials must be appropriate to the local technical level

CWD is involved in projects in the following countries:

Sri Lanka

In March 1977 the Wind Energy Utilization Project was started with financial support from the governments of Sri Lanka and the Netherlands. The execution is in the hands of the Wind Energy Unit of the Water Resources Board.
The project is staffed by Sri Lanka engineers, technicians and workers, while CWD experts provide assistance. About 150 windmills were produced in the last two years, mainly by local workshops. Part of these windmills were sold at subsidized rates. Presently a small 2-m diameter windmill for irrigation by small farmers is under development.

Republic of Cape Verde

Since 1981 CWD supplies two wind experts in a large renewable energy project with emphasis on wind power, executed by the Ministry of Rural Development. The project focusses on training of staff in installation, repair and maintenance of windmills.
A high-wind-prototype for waterlifting of 5 m diameter is under development.

WEU-I prototype irrigating in Sri Lanka

Pakistan

Stimulating contacts with Merin Ltd. in Karachi led to CWD's consultancy to start production of windmills. The WEU-I prototype developed in Sri Lanka was selected and in 1980 a CWD expert paid a three-month visit for technical assistance.

Tanzania

The Ujuzi Leo Industries in Arusha have been supported in improving their windmill design via a two-month course in the Netherlands and short-term expert visits.

Tunisia

In support of the ASDEAR (Association pour le développement et l'animation rurale) CWD supervised in 1980 the construction of three CWD 4000 prototypes as a start of production in series by a local entrepreneur.
In support of the SEREPT-company CWD designs a 5-m diameter windmill for water pumping, meant for series production.

Peru

As a part of an agricultural project, supported by the Netherlands Ministry of Development Co-operation, a CWD 2740 prototype has been built. Since 1981 technical backstopping has been given to a Dutch expert in a bilateral co-operation program.

Feasibility Studies

CWD has carried out feasibility studies on the use of wind energy in the following countries or areas.
Sri Lanka (1976), Cape Verde (1980), Tanzania (1977), The Sahel (1976), Djibouti (for GTZ, 1981), Yemen Arab Republic (1980), Sudan (1980), Maldives (for ADB, 1980), Kenya (1982), Netherlands Antilles (1982).

Explaining the particulars of windmill testing at the Asian Institute of Technology, Bangkok.

TRANSFER OF KNOWLEDGE

Local knowledge is gathered in country projects and during visits of experts from abroad. Particularly the failures of windmill projects in the past deserve great attention. A first analysis of the causes for failure resulted in the following list:
- import restrictions on spare parts
- lack of funds
- lack of local know-how and of care for maintenance
- introduction of (subsidized) electric and diesel pumps
- drop of ground water table
- reduction on the number of windmills, making repair a non profitable job
- fear for repairs on top of a high tower
- termination of production and of supply of parts by manufacturers.

Knowledge in wind energy technology and related fields is transferred by CWD to developing countries by:
- publications
- drawings and construction manuals of prototypes
- visits and consultancies
- education and training

CWD also functions as a clearing-house for information and experience with wind energy systems: the experience with the WEU I windmill in Sri Lanka has been transferred to Pakistan for example.

Another facet is the supply of experts for lecturing purposes such as for the six-month UN-ESCAP Roving Seminar on Rural Energy Development in 1977. In the summer of 1980 and 1981 CWD sent an expert to the Asian Institute of Technology, Bangkok, to give introductory and advanced courses on wind energy and to coach MSc students.

Installation of windmills on Cape Verde.

PUBLICATIONS

CWD has been issueing publications on various topics related to wind energy applications: feasibility reports, theoretical aspects, design of rotors, economics of windmills, irrigation with windmills, etc. (see CWD-publications list).
CWD publications can only be ordered by letter to CWD with payment in advance. Research institutes in Third World countries may ask for a copy of three publications free of charge.

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SHORT TERM MEASUREMENTS TO INVESTIGATE STARTING BEHAVIOUR OF WATER PUMPING WINDMILLS

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ABSTRACT

Short term measurements, ranging from 1 sec to 600 sec, have been carried out at the prototype CWD 2740 at the CWD testfield at Eindhoven University of Technology. These measurements are aimed to investigate the starting behaviour of water pumping windmills. In this presentation the effect of the averaging time and the selection of starting and stopping events from the total set of data, are treated.

INTRODUCTION

CWD (Consultancy Services Wind Energy Developing Countries) is an organization initialized and funded by the Netherlands' Ministry of Development Cooperation. It aims to help governments, institutes and private parties in the Third World in their efforts to use wind energy and in general to promote the interest for wind energy in developing countries. The emphasis of the activities of CWD is on water pumping windmills, coupled to single acting piston pumps. Participants of CWD are:

- DHV Consulting Engineers, Amersfoort
- Eindhoven University of Technology (Wind Energy Group)
- Twente University of Technology (Windmill Group)
- ILRI (Institute of Land Reclamation and Improvement), Wageningen.

CWD-designed water pumpers are in operation in Sri Lanka, Pakistan, Tanzania, Mozambique, Mauretania, Tunesia, Peru, Cape Verde and Ghana. Implementation projects are being carried out in Cape Verde and Sri Lanka, and are in preparation for Sudan, Kenya, Nicaragua, Somalia and Mozambique. Development of prototypes is mainly done in The Netherlands.
For field testing of water pumping windmills, CWD has testfields in Eindhoven, Vriezenveen (close to Twente University) and Almere (in one of the polders in the former Zuiderzee).

This paper deals with short term (less than 10 minute) measurements of windspeed and rotorspeed of the CWD 2740 prototype at the Eindhoven testfield. The starting behaviour in the field cannot be predicted correctly from laboratory measurements; this is mainly due to the rapid (period shorter than 10 minutes) fluctuations of windspeed and winddirection, and the response of the windmill to those fluctuations.

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*) Student at Eindhoven University of Technology. Department of Physics. The reported work was done as a traineeship at the Wind Energy Group, with guidance of Joop van Meel, Niko Pieterse and Paul Smulders.

Short term measurements can give more insight in this behaviour. The particular objective of this traineeship was to examine the effect of a starting hole in the piston on the starting behaviour.

STARTING HYSTERESIS

The power curve of a windmill coupled to a single-acting piston pump shows a starting hysteresis: the torque required to start the pump is π-times as high as the average torque, whereas the mill will continue to run (at gradually decreasing windspeeds) until the rotor operates in its maximum of the torque vs tip speed ratio curve (stopping windspeed). From steady-state analysis, it can be shown that: (Ref. 1):

$$\frac{V_{start}}{V_d} = \sqrt{\frac{\pi C_{Q_d}}{C_{Q_0}}} \quad \text{and} \quad \frac{V_{stop}}{V_d} = \sqrt{\frac{C_{Q_d}}{C_{Q_{max}}}}$$

where: V_d = design windspeed (windspeed at which the windmill pump combination has its highest efficiency);

V_{start} = starting windspeed (windspeed at which the windmill starts pumping water in a gradually increasing wind);

V_{stop} = stopping windspeed (windspeed at which the rotor stops in a gradually decreasing wind);

C_{Q_d} = rotor torque coefficient at design tipspeed ratio;

$C_{Q_{max}}$ = maximum rotor torque coefficient;

C_{Q_0} = rotor torque coefficient at zero tipspeed ratio.

When 10 minute measurements in the field are taken to obtain the overall power coefficient curve ($C_p.\eta$ versus windspeed), this hysteresis will be smoothed away: between V_{stop} and V_{start} the windmill is either running or standing still, depending on the windspeed history (see Fig. 1). The drawn curve was derived from windtunnel and pump test rig measurements, the dashed curve is an estimate of what can be expected in the field.

In order to decrease the starting windspeed, CWD-designed prototypes have starting hole in the piston of the pump: when the rotational speed is very low, water above the piston passes through this hole as the piston moves upwards, so the pump does not lift any water. The mill gains momentum in the downward stroke and begins the next upward stroke with a somewhat higher speed, etc. As soon as the piston reaches a velocity at which the pressure drop over the starting hole equals the pumping head, the mill starts delivering water.

At normal operating speeds, the pump will lose some water through the starting hole. The starting hole is usually designed in such a way that these losses at the design windspeed are 10%.

The starting torque required by the pump will be considerably lower, because the water column is not lifted. Consequently, the windpump will start delivering water at a much lower V_{start}, the hysteresis between V_{stop} and V_{start} will be smaller, and so (see Figure 1) the overall power coefficient curve will be better.

MEASUREMENTS

Short term measurements have been carried out with the CWD data acquisition system in use for 'normal' 10 minute measurements (Ref. 3). The quantities measured were the same as usual, with the exception that the water flow was not registered during these measurements; the configuration of the water measuring system is such that the time-delay of the measurements is too high and resolution not good for these short term measurements. The accuracy of the (for these measurements) most important signals (windspeed and rotor speed) is sufficiently good to take the measuring interval equal to the sampling time of the measuring system: 1 sec.
Tenthousands of 1 sec-measurements have been carried out of the CWD 2740 coupled to a single-acting piston pump, both with and without starting hole in the piston. The discussion in this paper will be limited to the influence of averaging time, and to how the starting and stopping events have been selected from the measurements.

EFFECT OF AVERAGING TIME

As the actual measuring time is 1 sec, we can imitate longer measuring times by calculating average values of the quantities in the elaboration programs. These averages can be obtained by taking a certain number of samples and calculate the average value in the formula program. This average value is worked with in the 'BIN SORT' or 'PLOT DATA' program. Then over the next amount of samples the average value is calculated. And so on. We used another averaging method in which an average value is obtained for each measuring point by calculating the average value for a certain number of preceding samples. This method shifts through the data and every sample is used more than once. For the case the averaging time is 10 sec both methods are compared (see Figure 2).

The results of both methods coincide as well as for the mean values as for the standard deviation. The advantages of the 'shifting' averaging method are that more points are available for 'BIN SORT', so resulting graphs have a smoother shape, and that the effect of averaging on fluctuations can be visualized by 'PLOT DATA'. In fact, the shifting averaging method acts as a low-pass filter. In Figure 3 this filtering effect is shown for some averaging times.
The effect of averaging times on bin sort curves is worked out for the following averaging times: 1, 3, 6, 10, 20, 60, 180 and 600 sec. The last three times, i.e. 60, 180 and 600 sec have only been used to compare fast measurements with measurements according to the standards of the IEA. In Figure 4 the resulting n-V curves are shown.

We find that the mean values coincide well. Only the standard deviation is influenced by averaging time, as could be expected. The standard deviation decreases for increasing averaging time. Especially for longer averaging times, when there is only a piece of a curve plotted, a systematic error can occur. This error, due to the bin sort procedure, is often described as the 'stopping effect', and makes the slope of a piece of curve to appear less rigid as when the bin sort procedure had handled the total curve. An analysis of this effect is given by Dragt (Ref. 5). The conclusion seems to be justified, that as far as the response time of the windmill is concerned, the interval of performance measurments could be decreased from 10 min. to 1 min.

SELECTION PROCEDURE

From the data now the starting and stopping events have to be selected. This was done in two ways: the monotonous increase or decrease of windspeed respectively rotor speed as selection criterion. Figure 5 gives an example (in time sequence presentation) of selection on rotor speed; Figure 6 on windspeed.
In Fig. 6 we see that then windspeed starts to decrease the rotor speed is still increasing for some time. Both phenomena are caused by the finite response time of the windmill on variations in windspeed and wind direction.
The results can be presented in a bin sort (see Fig. 7). For comparison purposes a graph is added in which the mean values of the three curves are plotted.
In evaluating the bin sorts we have to involve the frequency distribution for windspeeds during the measuring period. In this measurement series this means that the increase in standard deviation of the rotor speed in the windspeed region above 7 m/s is mainly due to the decreasing number of measuring data in that region.
The hysteresis region can clearly be seen from this figure. It appears that the distribution between starting and stopping becomes less with increasing measuring time, as expected. The method of data acquisition and elaboration as presented in this paper, has proven to be useful for analysis of the starting behaviour. The measurements will be continued.

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3. Henk Oldenkamp, Manual for a windmill measuring system based on Apple II micro computer, CWD, Wind Energy Group, Eindhoven University of Technology, Report R-647-D, 1984.

4. Jef Horijon, Starting behaviour of a water pumping windmill, Wind Energy Group, Eindhoven University of Technology, Report R-721-S, 1985.

5. J.B. Dragt, On the systematic errors in the measurements of the aerodynamic performance of a WECS by the method of bins, ECN, Netherlands Energy Research Foundation, 1983.

FIGURES

Figure 1: Basic form of overall power coefficient curve; the drawn line is obtained from results of wind tunnel and pump test stand, with the assumption of a constant torque pump and a linear $C_Q-\lambda$ curve of the rotor.

The dashed line represents the expected curve of field measurements (Figure taken from Ref. 2).

Figure 2: The effect of the methods of averaging upon BIN SORT elaborations.

a) Average values of separate blocks of 10 samples.
b) Average values obtained by shifting through the sample file and averaging over the last 10 samples.

Figure 3: Influence of averaging time on data. For longer averaging times fast fluctuations are more filtered. Index M means the shifting averaging method is used, the number indicates the averaging time (sec). V = windspeed, N = rotor speed.

Figure 4: N-V curves obtained with the 'shifting' averaging method averaging times t_{av}: 1, 3, 6, 10, 20, 60, 180 and 600 sec.

Measurements were performed on 19 Dec. 1984.

Figure 5: Example of selecting on rotor speed. For clearness we start from 10 sec averages (a). In (b) selection took place on increasing rotor speed and in (c) the decreasing rotor speed is regarded.

Figure 6: Example of selection on windspeed with accessory rotor speed. In (a) the original 10 sec averaged data is presented. In (b) the increasing windspeed and in (c) the decreasing windspeed is regarded.

Figure 7: The resulting bin sorts, when a selection is applied to the data. In this example we start from 3 sec averages. In (a) the increasing rotor speed is only regarded. In (b) only the decreasing rotor speed was accounted for. In (c) a comparing graph is shown in which only the mean values of the former bin sorts are plotted, the points (.) represent the increasing curve and (+) stands for the decreasing curve.

NOTE: Figures 2 through 7 taken from Ref. 4.

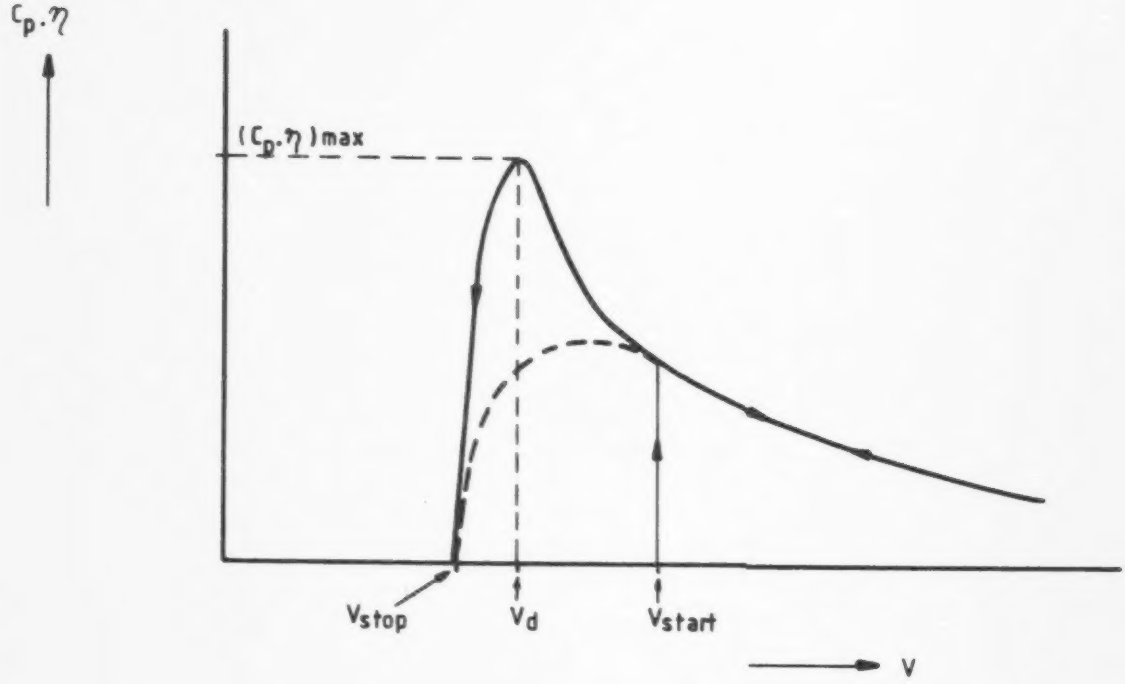

Figure 1

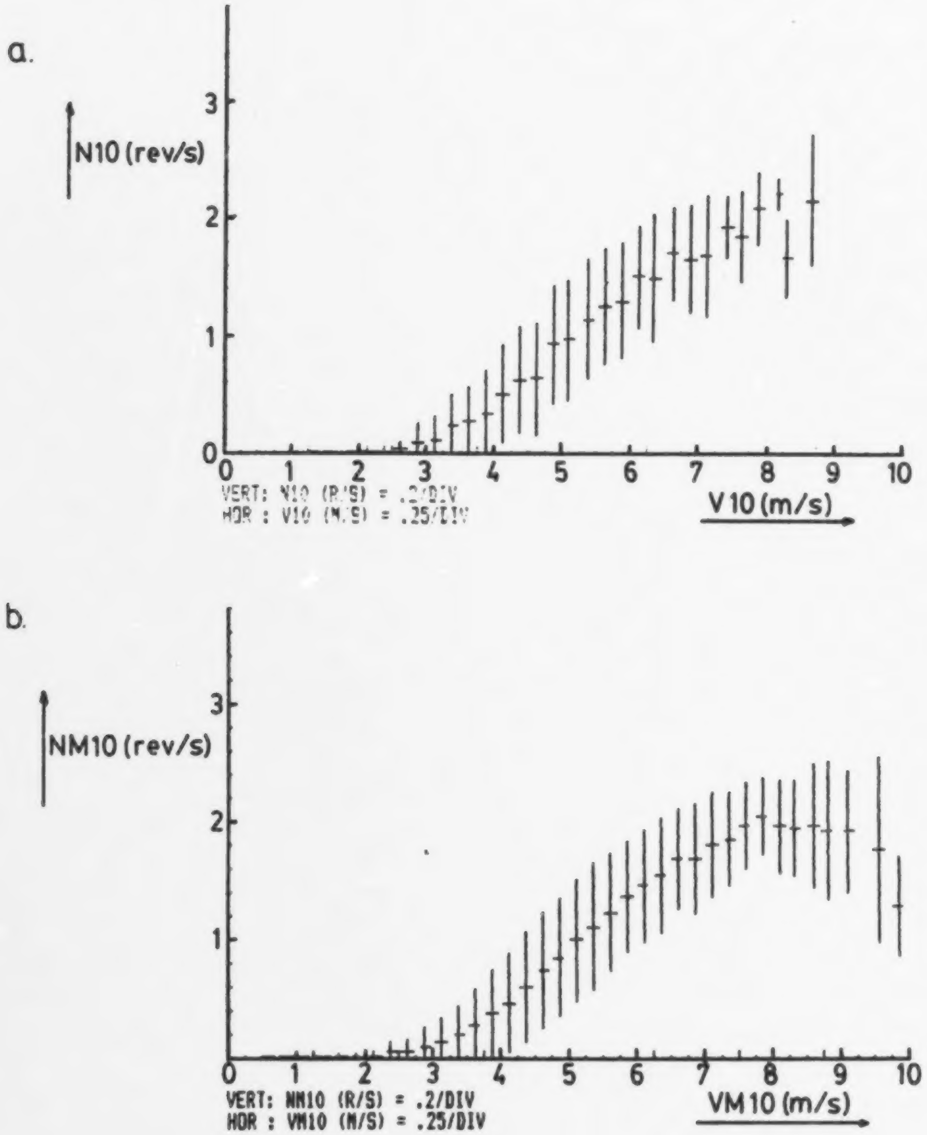

Fig. 2 : The affect of the methods of averaging upon BIN SORT elaborations.
a) Average values of separate blocks of 10 samples.
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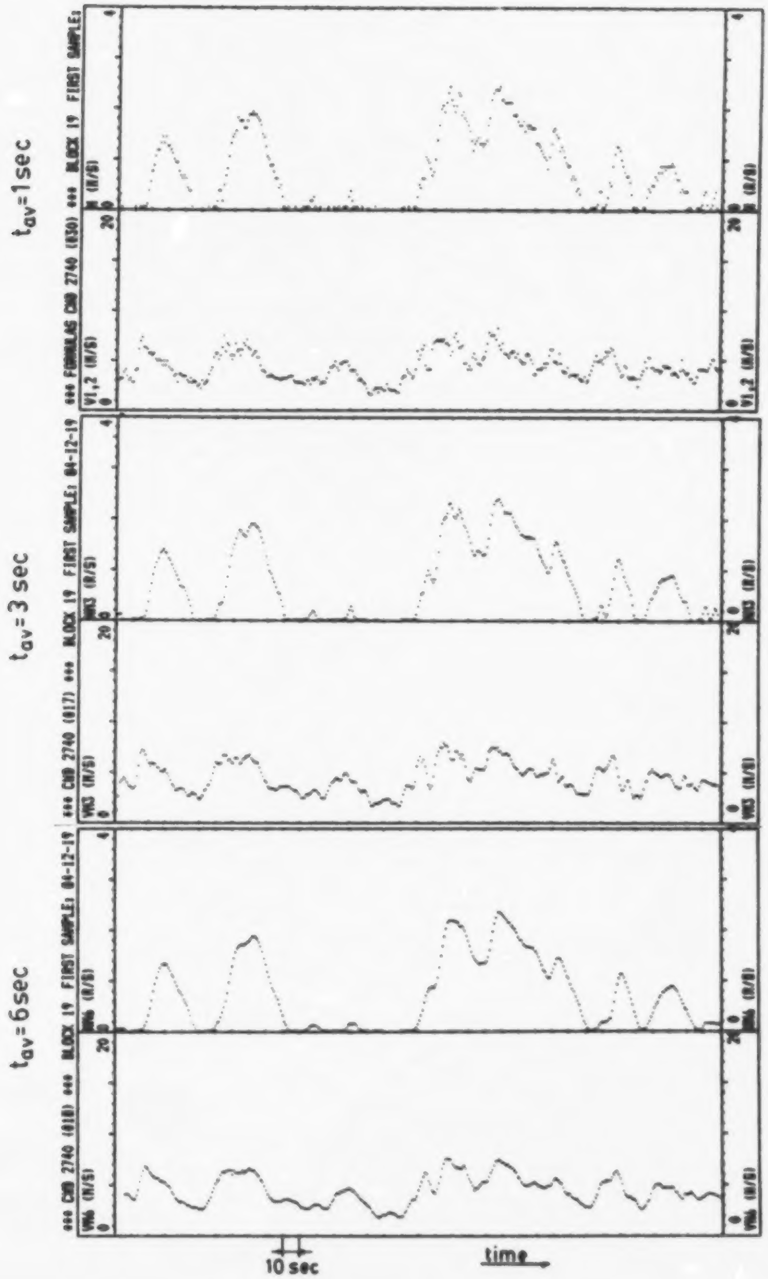

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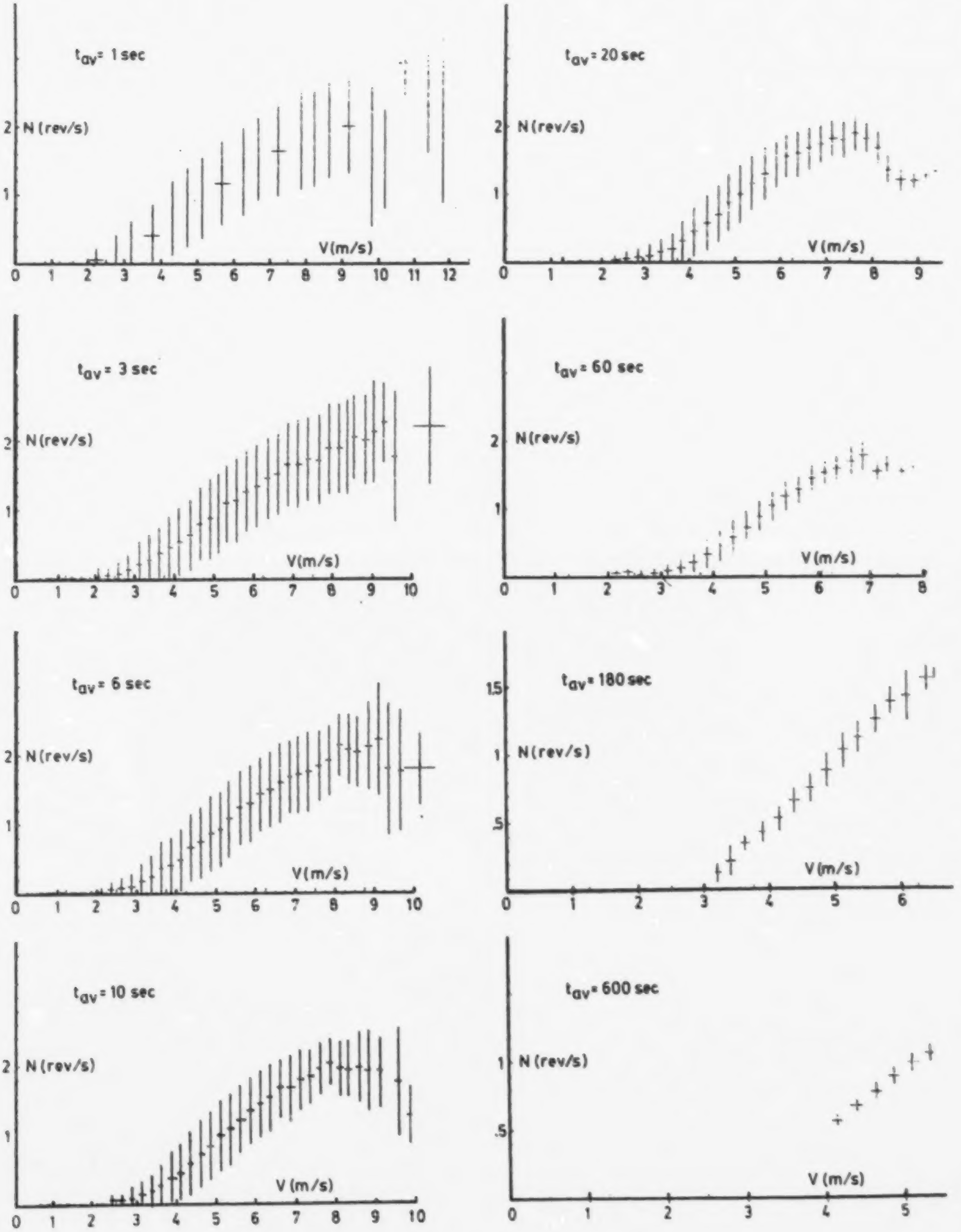


Fig. 4. : N-V curves obtained with the 'shifting' averaging method averaging times t_{av}: 1, 3, 6, 10, 20, 60, 180 and 600 sec. Measurements were performed on 19 Dec 1984.

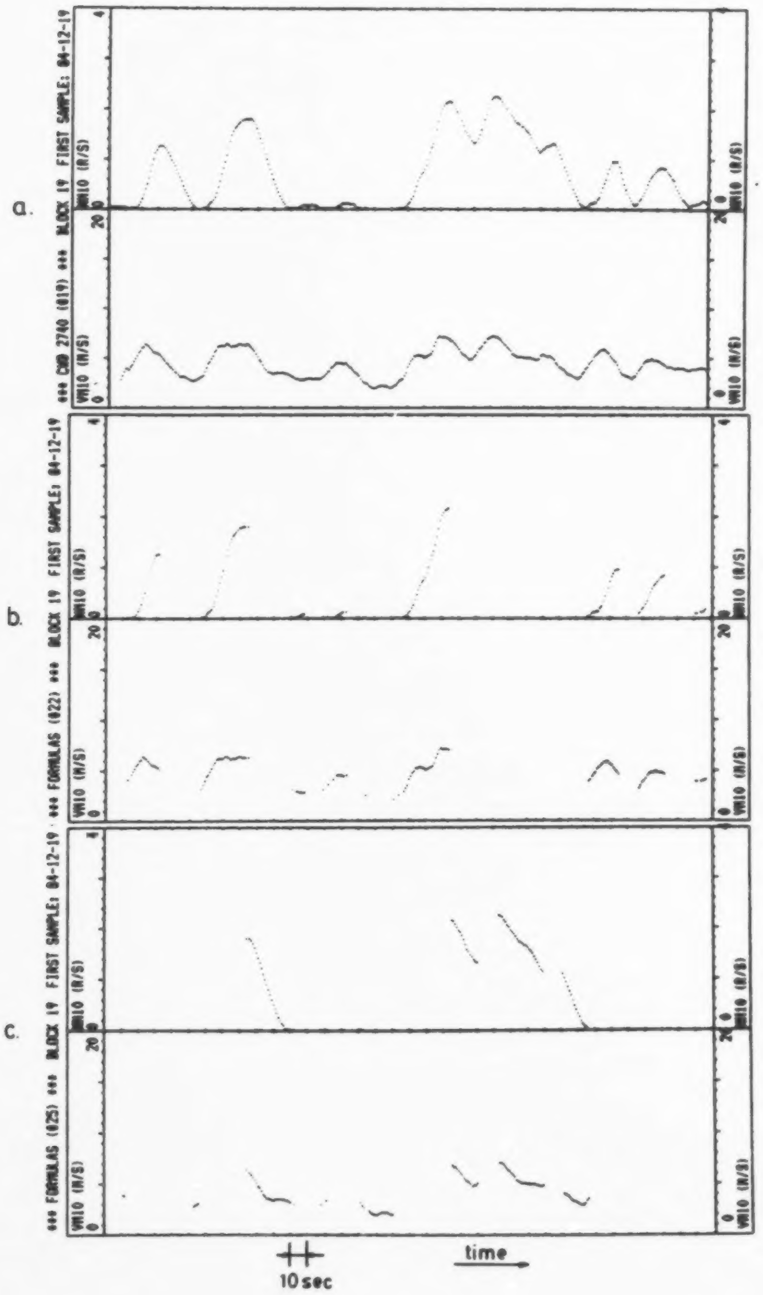


Fig. 5 : Example of selecting on rotor speed. For clearness we start from 10 sec averages (a). In (b) selection took place on increasing rotor speed and in (c) the decreasing rotor speed is regarded.

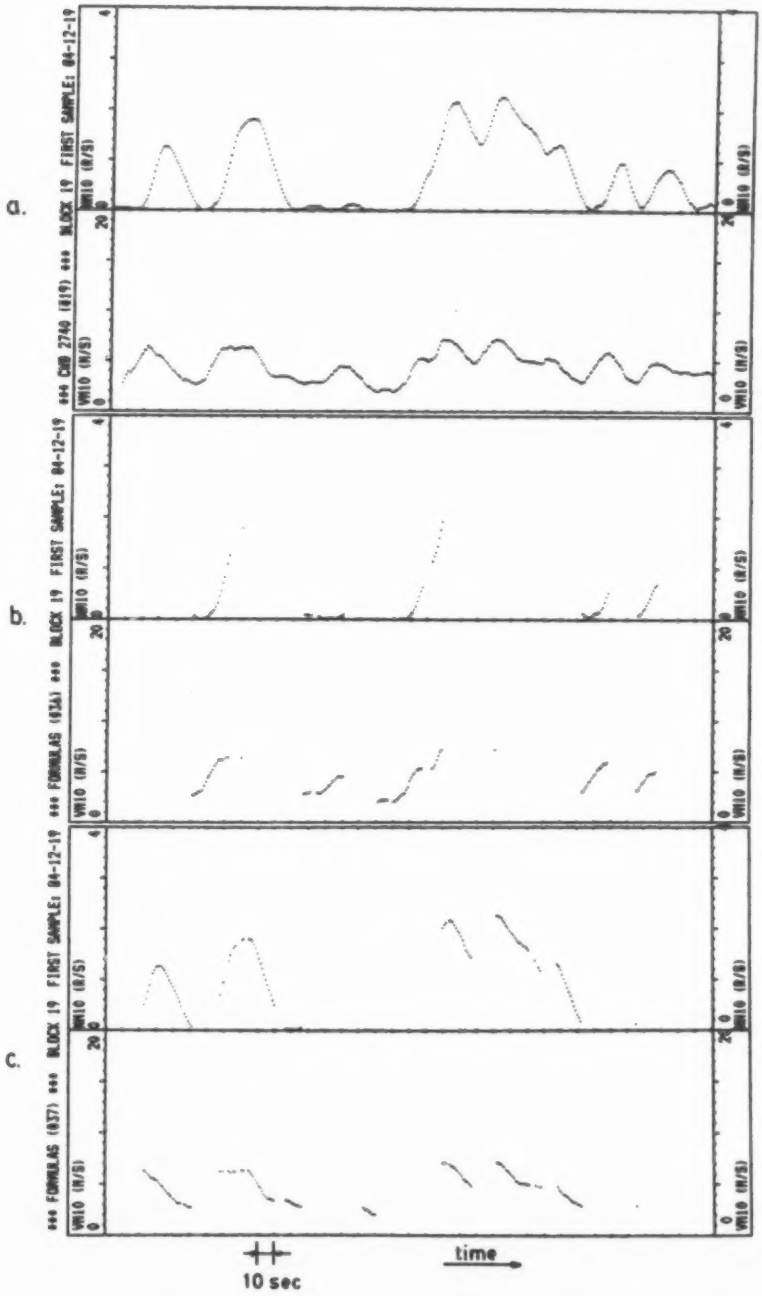


Fig. 6 : Example of selection on wind speed with accessory rotor speed. In (a) the original 10 sec averaged data is presented. In (b) the increasing wind speed and in (c) the decreasing wind speed is regarded.

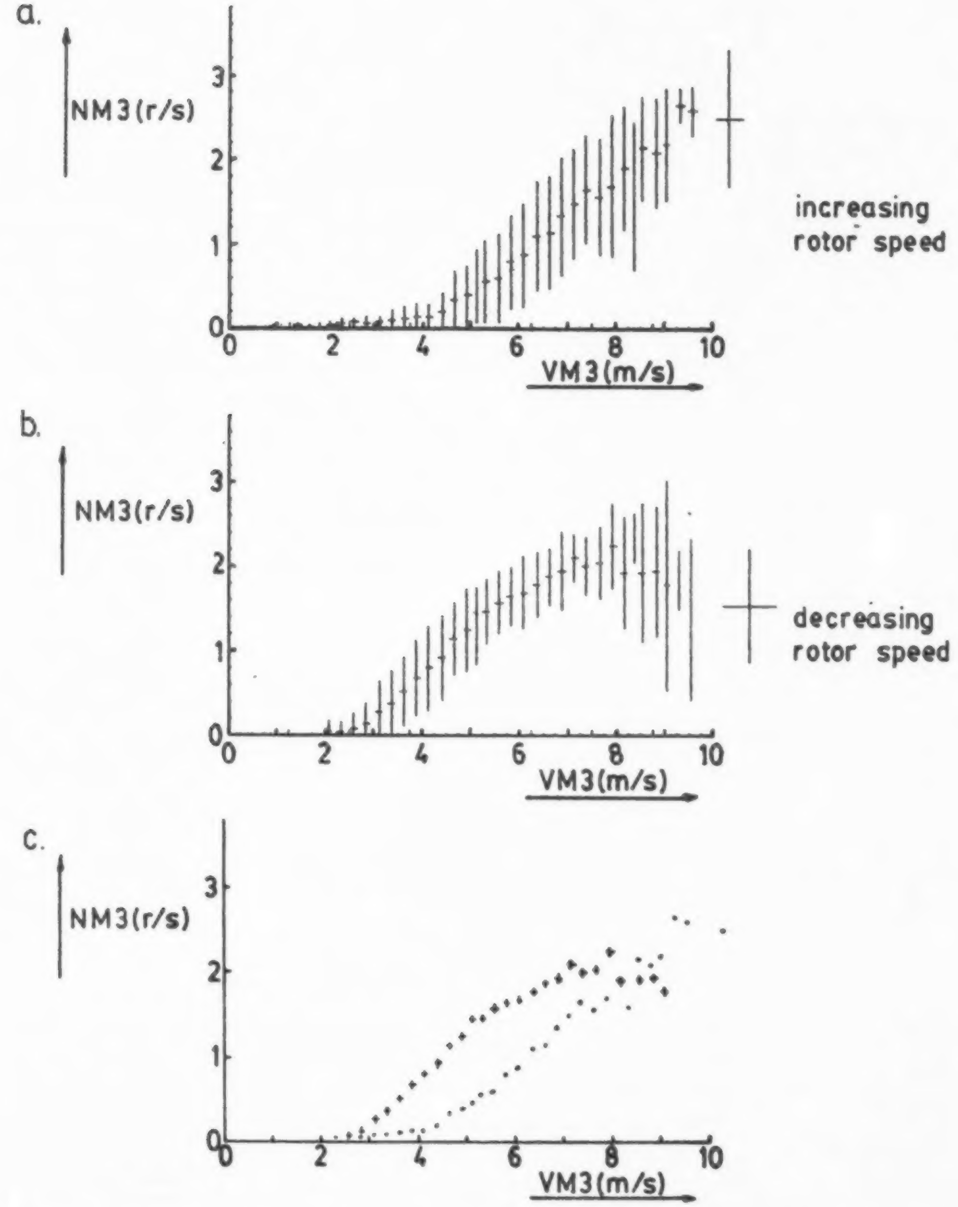
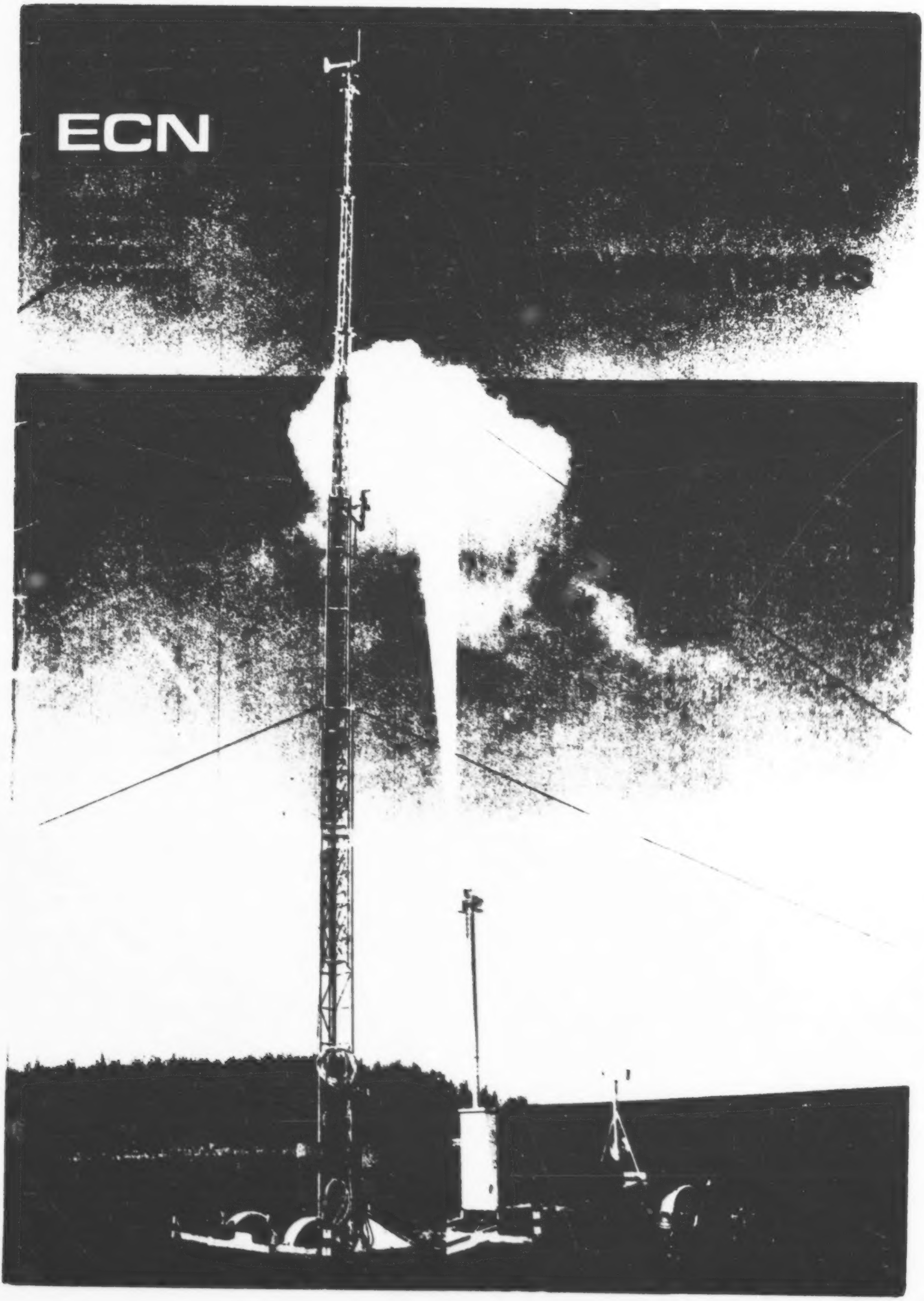


Fig. 7 : The resulting binsorts, when a selection is applied to the data. In this example we start from 3 sec averages. In (a) the increasing rotor speed is only regarded. In (b) only the decreasing rotor speed was accounted for. In (c) a comparing graph is shown in which only the mean values of the former binsorts are plotted, the points (.) represent the increasing curve and (+) stands for the decreasing curve.


ECN

Introduction

Before a wind turbine is brought on to the market years of work have been spent on developing it. This is a laborious process, involving continuous checking to ensure that the design is sound, that performance is in line with predictions, that the right materials have been chosen, that the estimated power output is realized and that safety and reliability are guaranteed.

For manufacturers of wind turbines, measurements and trials are necessary to create a good product. Users, too, often need measurements and trials of their machines, for example to obtain accurate power output data or to optimize control.

ECN and Wind Turbine Measurements

Taking measurements on wind turbines is a skill of its own. Years of experience and a substantial theoretical and practical knowledge are required for carrying out measurements yielding accurate, reliable results. The Netherlands Energy Research Foundation (ECN) having both the knowledge and experience and the required facilities, is regularly asked to execute such measurements.

Over the years ECN has developed various testing and measurement techniques for wind turbines, primarily as part of projects developed in connection with the National Research Programme on Wind Energy (NOW).

At an early stage in the NOW-programme - started in 1976 - an experimental wind turbine, the '25 metre HAWT' (Horizontal Axis Wind Turbine) was built; it was erected on the ECN site at Petten in 1981. It has a rotor diameter of 25 metres and a rated output of 300 kW. ECN developed an extensive measuring programme for the 25 metre HAWT with the object of collecting data on the functioning of wind turbines.

On the same site at Petten a test station for small and medium-sized wind turbines has been set up. Here turbines with a rated electrical output of up to about 200 kW can be put through extensive trials. Since its inception the test station has grown into a complete technical centre for wind turbines, involving besides the conducting of trials other activities such as certification and consultancy.
Also at the request of industry, ECN has developed facilities for carrying out trials and measurements at other locations as well. So for specific measurements a wind turbine does not necessarily have to be installed at the test station.

Field measurement is not a new departure for ECN, however. Under the NOW programme ECN has been conducting measurement programmes for various pilot projects in the Netherlands. The measurement programmes are adapted to the applications investigated in the projects.
This brochure describes specific measurements that can be carried out on-site for manufacturers and owners of wind turbines.

Field Measurements

Field measurements can range from comparatively simple measurements of noise levels to an extensive investigation in which the operation of a wind turbine is observed in detail.

Manufacturers appeal to ECN at various stages of product development in order to verify design assumptions. A manufacturer may also require certain data for a customer or a licensing authority.

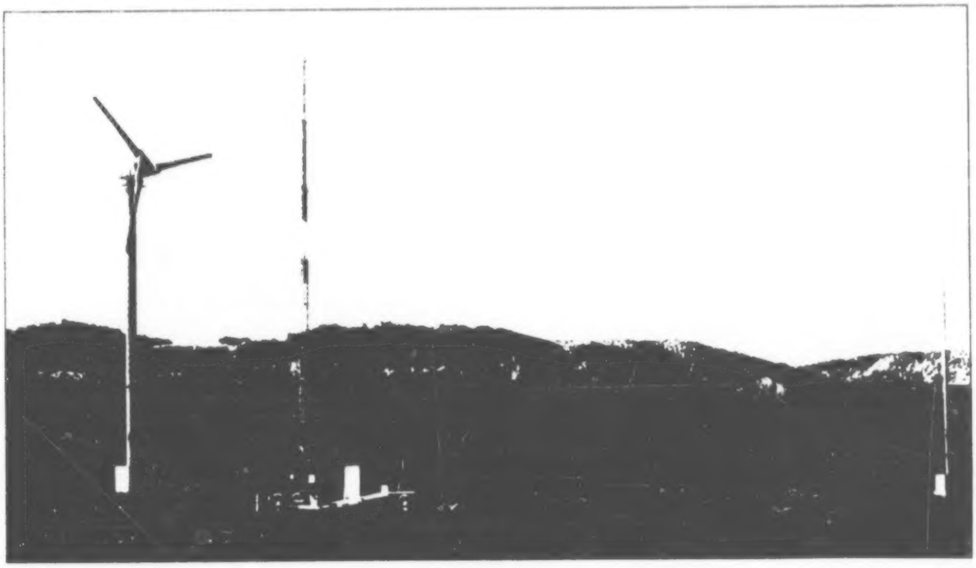
For users of wind turbines it is important to determine the wind regime on their site before buying one of these machines. After purchase ECN can lay on acceptance tests to check whether the turbine has been delivered in accordance with the specifications.

Alternatively, the owner may wish ECN to verify whether he is making optimum use of the wind turbine.

Apart from users and manufacturers others may also be interested in wind turbine measurements; licensing authorities, for example, sometimes carry out or commission measurements in order to check the noise level of a wind turbine.

Institutes engaged in research in the field of wind energy may need measured data for their own projects. This applies not only to technical measurements carried out on the wind turbine itself but also to measurements of wind and noise characteristics.

Application measurements at Camperduin, the Netherlands (NOW pilot project).



Field measurements

Power performance measurements
- Yearly energy production
- Power curve (P-v)
- Aerodynamic efficiency (C_p-λ)
- Power fluctuations
- Control characteristics
- System optimization
- Fuel saving

Mechanical measurements
- Mechanical stresses
- Axial rotor forces
- Design assumptions

Vibration analysis
- Free vibration frequencies
- Resonance phenomena
- Rotor imbalance

Noise measurements

Determination of blade and rotor geometry

Acceptance tests
- Safety systems
- Control systems
- Specifications

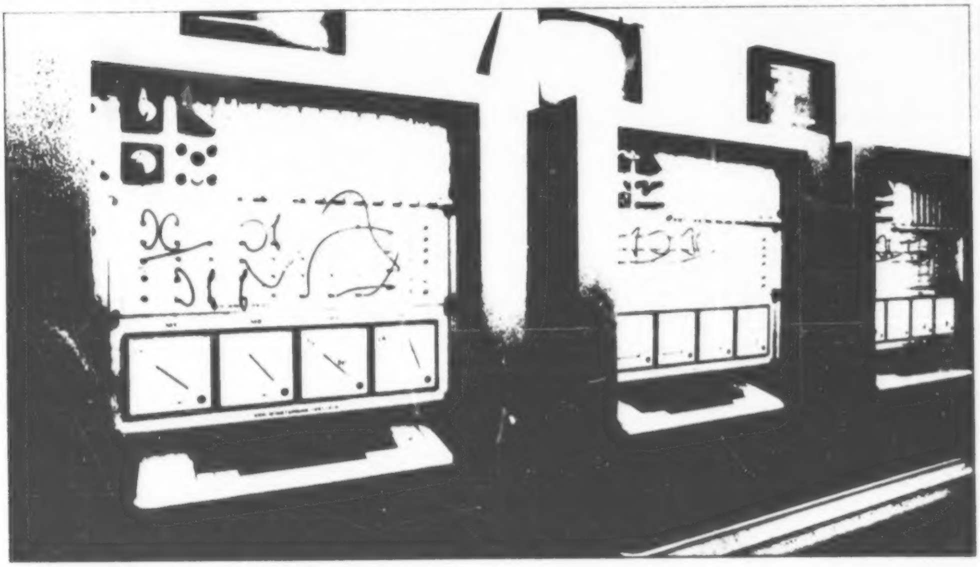
Determination of electrical characteristics
- Harmonic distortion
- Reactive power
- Cut-in phenomena

Application measurements
- Load pattern
- Matching demand and supply
- Load management

Measurement of wind regime

Standard test

Mobile data acquisition systems



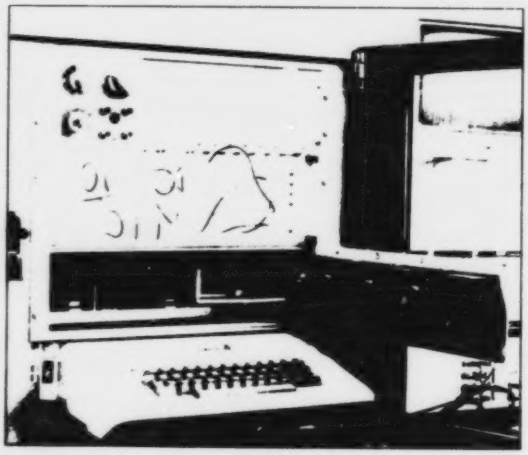
Performance Measurements

Information about performance characteristics is essential for an assessment of the quality of a wind turbine. ECN has developed a mobile data acquisition system by means of which a variety of performance measurements may be carried out.

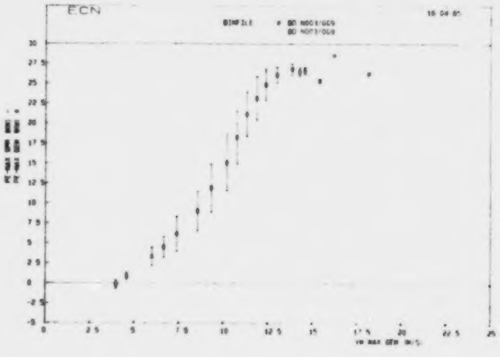
The principal purpose of the measurements is to determine the relationship between wind speed and turbine variables, and between the turbine variables themselves. The system may be used to define the relationship between wind speed and actual electrical output (the P-v curve) and between wind speed and rotor speed. From the P-v curve and the local wind regime the expected yearly energy production can be calculated.
The data acquisition system can also be applied for measurements on independent systems, for example for the optimization of control characteristics of wind/diesel systems or for the determination of the fuel savings achieved.

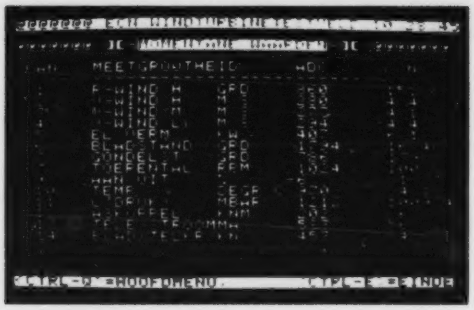
The data acquisition system is an aid that can be rapidly set up for use. With it the chief characteristics of the wind turbine can be established and the result of adjustments - to e.g. the control strategy - can be determined. The system proves to be a helpful instrument to be used in the development of wind turbine systems. The data acquisition system is a flexible device and can therefore be used for measurements on different types of wind turbines.
Adjustment of the measurement range to the type of wind turbine under test is a simple matter. The accuracy of the measurements is high: most signals are processed to a degree of accuracy of within 1%.

Above the keyboard of the Apple II microcomputer used to operate the data acquisition system, the disk drives and the modem are shown.



Results are presented clearly and conveniently: here a P-v curve with average values and corresponding dispersion.





Actual measured values displayed on the screen of the data acquisition system.

Hardware

The various relevant values are measured with sensors. Below a survey is given of the standard variables which can be measured using the sensors of the data acquisition system. For special measurements various other sensors can be used for e.g. the determination of oil pressure and oil flow in wind turbines with hydraulic transmission.

For wind measurement a mobile wind measurement mast is available for clients who have no suitable mast of their own.

Standard variables for which sensors are provided in the data acquisition system:

- wind speed
- wind direction
- air temperature
- air pressure
- yaw angle
- rotor speed
- electric power
- reactive power
- electric current
- mains voltage

The measured signals are processed and recorded by the electronic equipment housed in a lockable compartment. The signals are electronically converted for processing on an Apple II microcomputer. The processed data are stored on diskette and may be transmitted periodically to ECN for further processing via a built-in telephone modem.

Four analog indicators display the actual measured values of the most important variables. Finally, more extensive measured data may be called up on a separate screen.

Software

ECN has developed a special software package for the data acquisition system, the UMP-12 (Universal Measuring-program Package).

UMP-12 consists of a number of programs supplemented by some utility programs.

When installing the data acquisition system ECN first calibrates the apparatus with the help of a routine included in the package. During measurement UMP-12 collects and records the measured values. For a specified time, usually 10 minutes, the average values, the dispersion and the maximum and minimum values are determined. These series are finally stored on a diskette. A survey of the series of measurements may be called up on the screen.

After 1 to 2 weeks a diskette will be filled. The measured data can then be transmitted via the modem to Petten or the diskette itself may be sent there. At Petten the measured data are then processed. ECN has developed an evaluation package with which the data may be rapidly processed. The result is a set of tables and graphs supplying all the information desired. The client will usually have the interim results at his disposal within a few days.

Mechanical Measurements

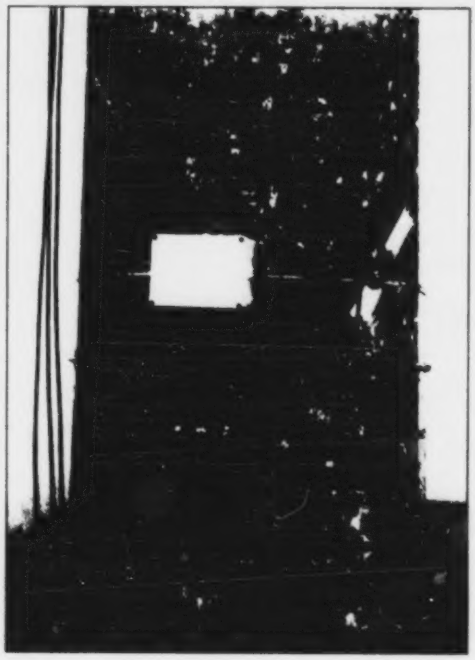
A wind turbine has to absorb heavy loads. The wind exerts forces on most parts of the machine. This can lead to heavy stresses on the materials used, particularly when the turbine is operating. In principle, the design of a wind turbine enables it to withstand forces exceeding those that are expected. Excessivity may, however, result in unnecessarily heavy (and therefore expensive) constructions. Therefore, it may be well-advised to find out whether the actual forces might not be lower than was assumed at the design stage.

ECN has a variety of facilities for carrying out mechanical measurements.

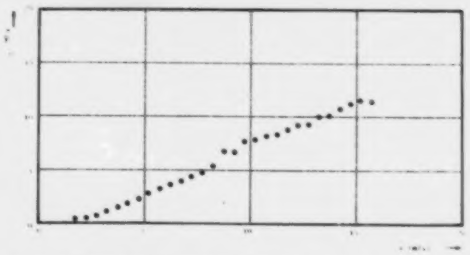
For measurements on small and medium-sized turbines strain gauge bridges are added to the mobile data acquisition system (see page 4). By fixing strain gauges to the desired spots, the system can be used to determine the mechanical stresses imposed on various components of the turbine.

Using this technique ECN has developed a relatively simple method for calculating the axial rotor forces using measurements taken at the foot of a turbine tower.

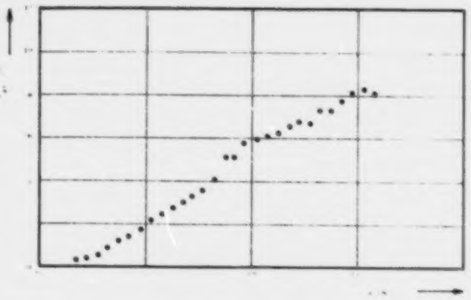
Strain gauges on the tower of a 15 kW turbine.



Mechanical stresses measured on the tower of a 55 kW turbine.



Axial rotor force calculated from measurements on the tower of the same wind turbine.



Sometimes the mechanical loads cannot be determined sufficiently accurately with the extended data acquisition system. This is the case, for example, when measurements have to be taken on the revolving rotor. Measurements of this kind require complicated apparatus. For instance, a telemetry system is needed for wireless transmission of the measured data from the rotor.

ECN has such apparatus available at its test station and for field measurements. A mobile test station incorporating all the necessary equipment is also available.

Extensive Measurements

The most extensive mechanical measurements are no standard procedure but are adapted to the turbine and to the client's requirements.

If a large series of design data has to be verified - such as free vibration frequencies, mechanical stresses, forces and moment of torque - equipment is used similar to that developed for the 25 metre HAWT. The measured data are processed on the PDP-11 computer system of the 25 metre HAWT and with the software written for that machine.

Generally a measurement programme of this kind, which takes about a year to complete, is only appropriate for large wind turbines or extensive research projects.

ECN is carrying out an extensive programme of mechanical measurements on Pioneer I, a 15 m vertical axis turbine in Amsterdam.

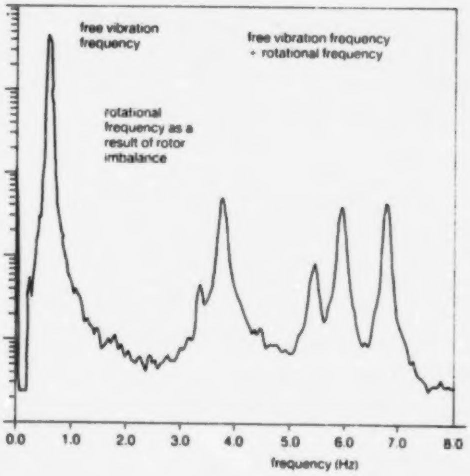
Vibration Analysis

If a free vibration frequency of a wind turbine component coincides with, for example, the rotational frequency of the rotor, violent vibrations may occur shortening the life of the turbine and increasing the risk of serious damage. This is especially liable to be a problem with wind turbines of variable rotor speed.

ECN utilizes measurement techniques which make it possible to measure and analyze the dangerous interaction between rotor and structure. This is especially necessary when calculations show that the free vibration frequencies and the rotational frequencies are close together. These calculations are based on certain asssumptions, so there is a risk that the real frequencies may be closer to one another than the calculations suggest.

The measurement activities usually take one or two days. A number of acceleration sensors are placed on the tower and these transmit analog signals via amplifiers to a tape recorder. The tape is analyzed by ECN at Petten. Using a computer program known as FAST the vibration pattern is converted into a spectrum of vibrations which gives a clear picture of possible interaction between rotor and structure.
In measurement operations of this kind ECN generally cooperates with the Dutch National Aerospace Laboratory (NLR).

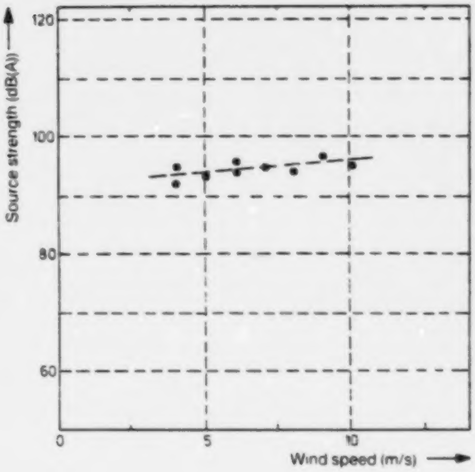
Acceleration sensor mounted on the turbine tower.



Frequency spectra of a variable rotational speed wind turbine in operation (blue) and at rest (black).

Noise Measurements

Noise measurement.



The source strength of a wind turbine in operation is usually practically independent of the wind speed.

In the Netherlands, in connection with the licensing of industrial installations, standards are laid down for permissible noise levels. In order to obtain a clear picture of the noise pollution, both the background noise at different wind speeds must be measured and the noise caused by the wind turbine itself.

In cooperation with ECN, the TNO-TH Institute of Applied Physics (TPD) has developed a simple measurement method whereby measurements are taken at eight positions around the turbine, four at a distance of one and a half times the rotor diameter and four at a distance of three times the rotor diameter.

The data are analyzed in the light of the current regulations with the help of ECN's EGW (Evaluation of Wind Turbine Noise Measurement software package.

With wind turbines of constant rotational speed the sound production appears mostly to be more or less independent of the wind speed (see graph). The turbine noise is then most distinctly audible at low wind speeds. For licensing authorities, therefore, the noise production at low wind speeds (for example 4 m/s) is often crucial. The duration of the noise measurement operations may then be limited to 1 or 2 days.

Noise production is characterized by source strength. That is a characteristic quantity indicating the noise produced by the turbine, independent of surroundings or distance from the turbine. Using this value the noise level at any location and at any distance can be calculated. The licensing authority can then compare this level with the level permitted at the location.

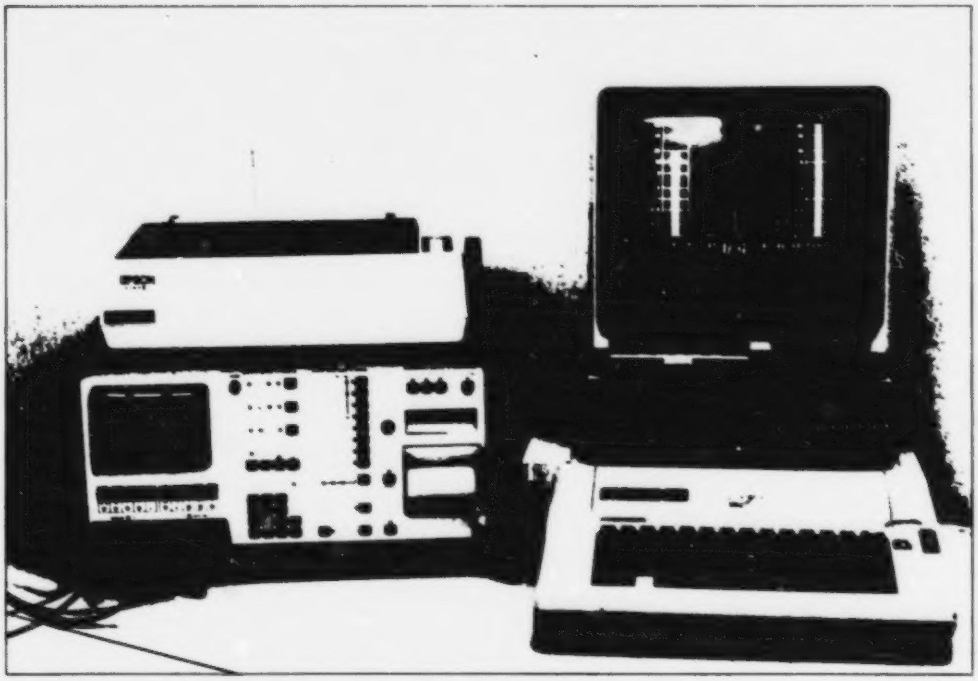
Determination of Electrical Characteristics

The electricity generated by a wind turbine must meet certain quality requirements. Equipment powered by the electricity generated will have its own voltage and frequency requirements. For connection to the public grid the electrical energy must meet certain standards.
Relevant factors are the reactive power, the harmonic distortion and the cut-in currents.

Measurement of these values usually takes 1 or 2 days.

The measurements are carried out with special equipment, such as a harmonic analyzer, in combination with an Apple II microcomputer. This equipment measures the harmonic voltage and current distortions. The reactive power and the main voltage are also determined as functions of the electric power supplied. Moreover, any cut-in peaks can be determined. Finally, checks are carried out to ascertain whether the electrical installation satisfies the regulations laid down by the utilities.

Harmonic analyzer with data processing equipment

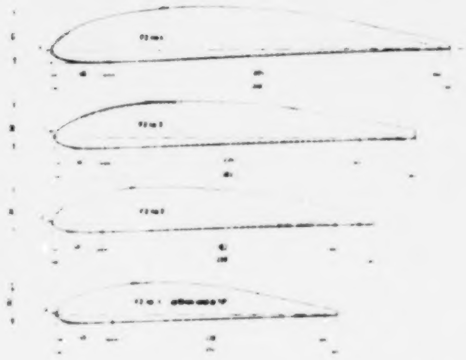


Determination of Blade and Rotor Geometry

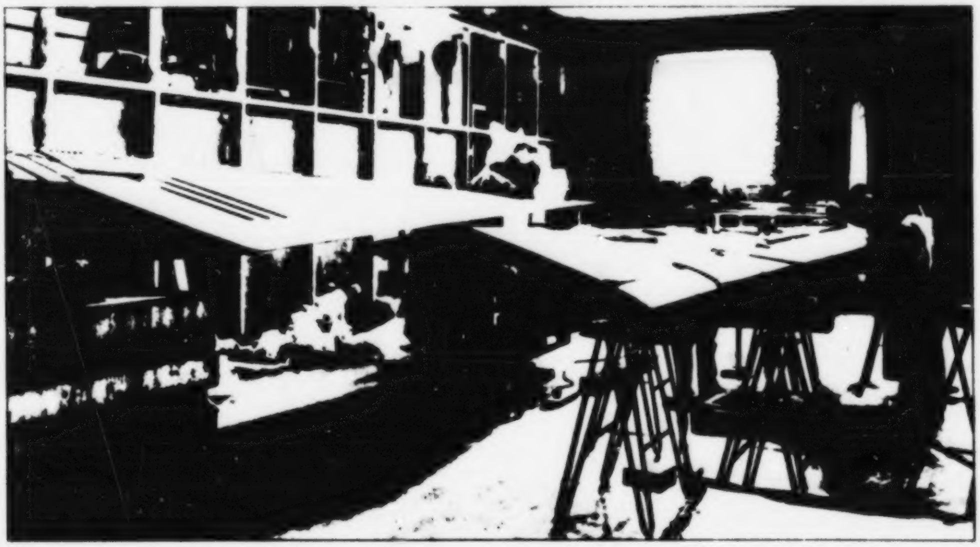
When a wind turbine manufacturer has a rotor made to order, he may have a blade profile measurement taken to check whether the rotor manufacturer has complied with the specifications. Rotor manufacturers use these measurements to check their products.

Moreover, the exact geometry of the rotor can be established by ECN. Such an investigation includes determination of the symmetry of the rotor. Usually a check is carried out simultaneously to ascertain whether the blades are connected to the hub at the correct angle. Specific attention is paid to the matching of the blade tip angle to the specifications and to the pitch angles of all the blades being identical.

Determination of the blade or rotor geometry takes 1 to 2 days.



Above: Measured blade profile at various distances along its length (sections per specification shown in blue). Below: Measuring of blade profiles.



Acceptance Tests

The purchaser of a wind turbine can have an acceptance test carried out to check whether the machine is built to the manufacturer's specifications.

A function test may also be carried out to check whether the control and safety systems function well in practice and comply with the current regulations and standards. In the function test, for example, the starting and stopping procedures are assessed under normal operating conditions. In addition the operation of the safety circuits is tested during normal operation and in case of a load cut.

It is important that it should be possible for any component of a wind turbine to fail without causing an unsafe situation. To check this a given safety device is deliberately put out of order. Then a situation is created in which the safety device ought to intervene. Another system should then keep the rotor speed within acceptable limits.

At high wind speeds the control system must limit the power produced to the rated output. This, too, is checked.

These types of test generally take 1 to 2 days.

In a function test the safety systems are tested in practice to existing standards. The turbine in the foreground did not meet those standards.

Application Measurements

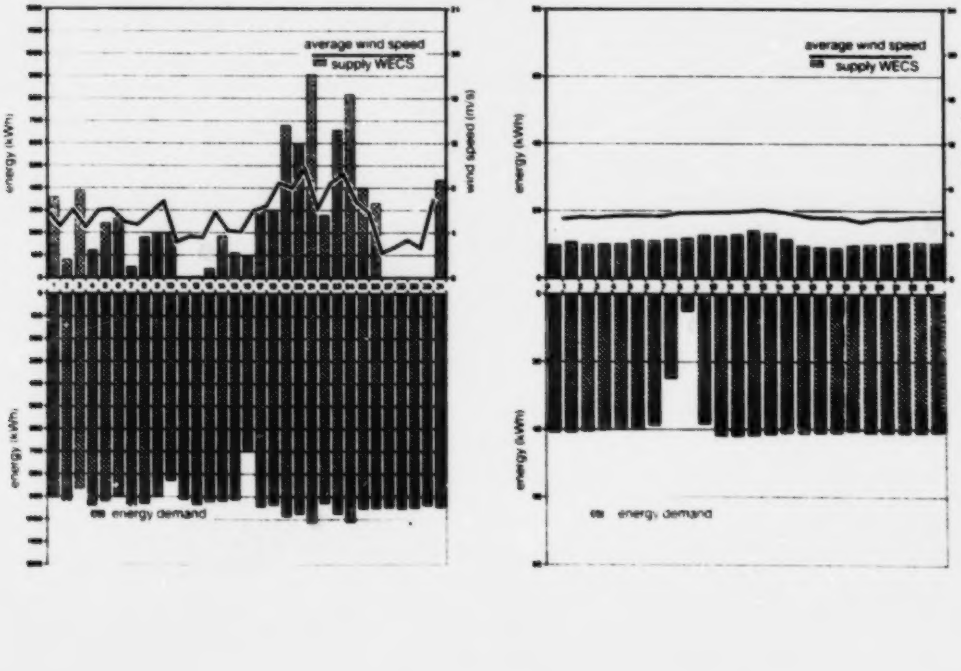
Buying a wind turbine only makes sense if the energy produced can be profitably used. Energy demand and supply must be matched as efficiently as possible.

It is therefore wise, before undertaking the purchase, to analyze the energy demand (per hour and per month) and to compare it with the performance data claimed by the manufacturer.

Even if the wind turbine is already in place a comparison of this kind may be sensible. The adjustment of the control mechanisms to the energy demand can often be improved, which eventually results in a higher power performance. An investigation of this kind sometimes demonstrates that it would be worthwhile incorporating some kind of storage into the system (e.g. storage of energy in batteries or as heat or cold).

For measurements of this kind, which take several months, ECN uses the data acquisition system described on page 4 or a similar system. The measured data are analyzed with a special computer program which produces surveys of, for example, energy production and consumption, frequency distributions and power performance.

Left: Monthly record of energy produced (top section) and energy demand (bottom section) per day.
Right: hourly averages in the same month.



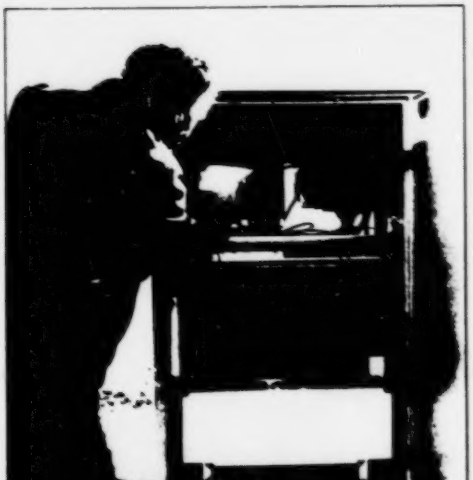
Measurement of Wind Regime

It is important both for potential wind turbine users and organizations engaged in wind energy research to have data on the wind regime at a particular location. Such information is essential for estimating the energy output of a wind turbine.

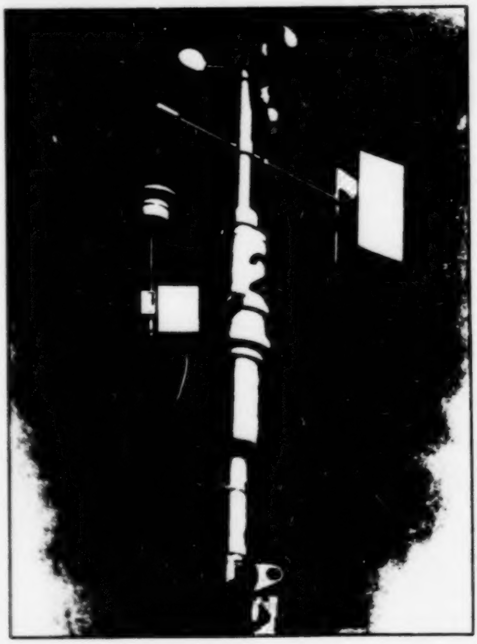
Using recently developed calculation models, the annual wind energy supply almost anywhere in the Netherlands can be predicted fairly accurately. A prerequisite is that the determining factors (location, type of terrain, presence of obstacles) can be clearly described. If this cannot be done, additional measurements must be taken.

The results of wind regime measurements always have to be corrected on the basis of known long-term data, because the variation in annual wind energy supply is very great. So the measured data are fed into a calculation program which corrects the values and, on the basis of measurements over a limited period, usually three months, produces an estimate of the annual wind supply at the location in question.

Apparatus for measurement of wind regime.



Combined anemometer and wind direction recorder, and a thermometer.

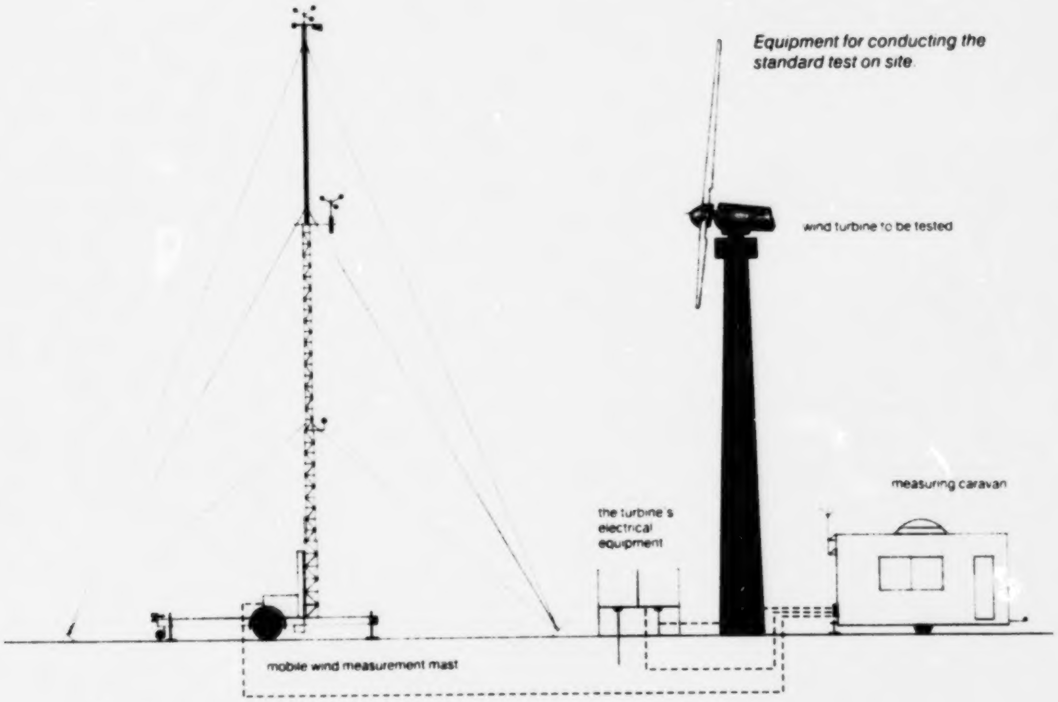


Standard Test

All measurements described so far are related to specific aspects of wind turbines. Sometimes a client, usually a manufacturer, has a need for a comprehensive trial of a wind turbine. If so, he can have a 'standard test' carried out by ECN. This test is a package of investigations performed in accordance with a fixed procedure. The advantage of this is that the standard test provides a complete description of a given type of wind turbine, drafted in agreement with national and international standards.

The standard test has been developed under the National Development Programme for Wind Energy and is the basis for trials at the ECN test station.

Thanks to the mobile equipment ('mobile test station') illustrated below, the standard test may be conducted at any location. This may be desirable if there is no place on the test station or if the turbine to be tested is too large to be set up there. Depending on the quality and nature of the wind turbine (interim modifications are possible), the standard test takes from 6 months to a year to complete.


wind turbine to be tested
measuring caravan
the turbine's electrical equipment
mobile wind measurement mast

Equipment for conducting the standard test on site.

Costs

A substantial proportion of the facilities described in this brochure has been achieved under the National Development Programme for Wind Energy. This programme is coordinated by the Management Office for Energy Research (PEO).

When carrying out measurements with these facilities, ECN in principle charges the costs to the client in consultation with PEO considering not only the amount of work done but also the nature of the investigations.

Further Information

Further information may be obtained from:

ECN Wind Turbine Test Station
P.O. Box 1
1755 ZG Petten
Holland
Phone +31 / 2246 4949

Realization de Boer & van Teylingen The Hague The Netherlands

TESTING PROGRAM AND WINDPOWER ACTIVITIES AT CHALMERS

Ola Carlson

Department of Electrical Machinery
and Power Electronics

Chalmers University of Technology
Göteborg, Sweden

1985

1. INTRODUCTION

The wind energy research activities at the department started back in 1975 with some theoretical studies of electrical machines in transient operation. Later on these studies were put into practice at the 70 kW Swedish test windmill in Kalkugnen. There was also some electrical system work done for the two Swedish prototypes at Maglarp, 3 MW, and Näsudden, 2 MW.

Today the activities have been concentrated on three fields:

study of electrical systems and components for large WECS,

evaluation of small windmills together with development of measuring technique and

research and development of autonomous wind-diesel systems.

2. THE TEST STATIONS AT FISKEBÄCK AND HÖNÖ

At the Fiskebäck test station the evaluation of a 15 kW, 8.5 meter rotor diameter wind turbine from SVIAB, Swedish Wind Energy Industries Inc., is nearly finished. The evaluation has a standard part with a power curve and an electrical part which deals with the thyristor controlled connection of the induction generator to the grid. How the control system operates is described in Ref.[1]. The inrush current which appears when the generator is connected to the grid is limited by the thyristors. The measurings in Fig.1 show the inrush current, when the turbine is operating.

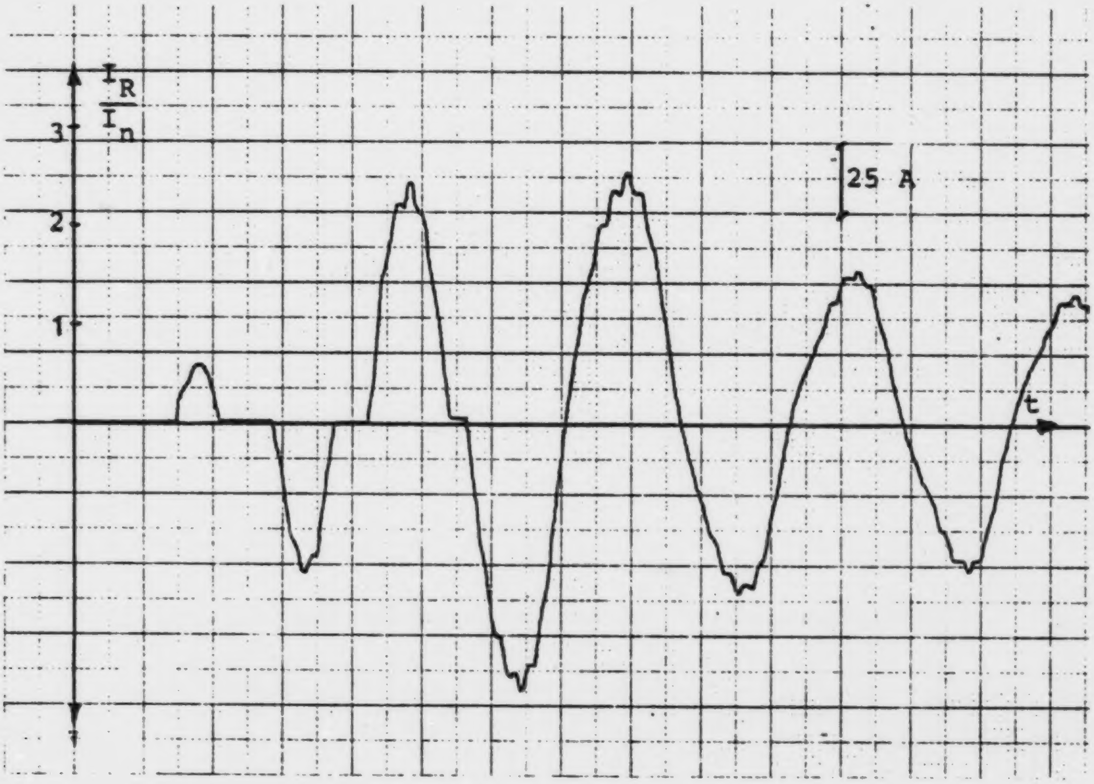


Figure 1: The inrush current of the 15 kW induction generator.

To get better wind conditions and to derive advantages from a test equipment concentrated to one place, the acitivities at Fiskebäck will be moved to the new test station at Hönö, see map of the Gothenburg archipelago.

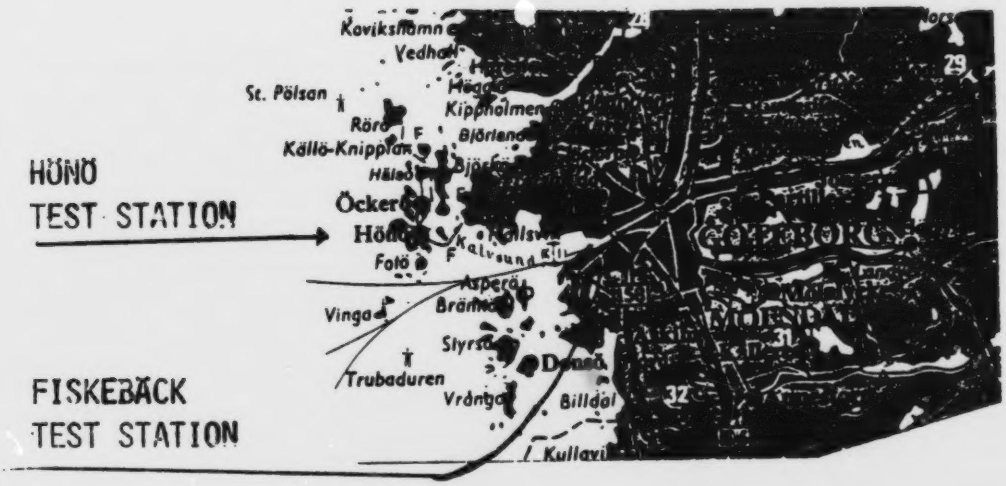

HÖNÖ
TEST STATION
FISKEBÄCK
TEST STATION
Vedholm
St. Pölsan
Kipholmen
Rörö
Björlanda
Källö-Knippla
Hälsö
Öckerö
Hönö
Kalvsund
Fotö
Asperö
Vinga
Brännö
Styrsö
Donsö
Truburen
Vrångö
Billdal
Kullavik
GÖTEBORG
29
31
32

Figure 2: The Gothenburg archipelago with the test stations at Hönö and Fiskebäck.

The activities at the Hönö experimental windmill are now going into a phase where variable speed systems will be studied. During the last 1,5 year the windmill has operated as a standard windmill. The operation has turned out well with the exception of a few problems with the hydraulic system.

Coming autumn we intend to install a new control system. This system is based on a micro processor and it will be a step further to an electrical system for variable speed on the turbine. The work with the new control system will be done together with the National Defence Research Institute, Division of Guidance & Control. Parallell to this work at the test station, theoretical and experimental work will be carried out at the department to build up an electrical system for variable speed operation.

At the test stations preparatory work is going on to test the two windmills from SVIAB, Swedish Wind Energy Industries Inc. The windmills are :

1.5 kW, 2.8 m rotor diameter turbine for battery charging
and
5 kW turbine for grid connection.

Near the test station (see map) the Swedish company QUEST DATA AB is planning to erect a 75 kW Vestas windmill. They will mainly test new control strategies as well as special control design which is a growing part of their activities. Further on they are going to work with windmills in autonomous systems with power electronic components.

3 WIND DIESEL SYSTEMS

The wind-diesel projects started at the department in 1983 with a small project for the Swedish State Power Board. The work has developed into a collaboration project with Riso National Laboratories, Denmark.

The aim of this collaboration is to construct, investigate and evaluate an autonomous wind-diesel system with electrical energy storage. The development and construction of the system and the laboratory tests will be carried out at Chalmers, while the field tests and evaluations will take place out at Riso.

The components of the system are as follows: a windmill with an asynchronous generator, a power regulating unit, an accumulator, two convertors, a diesel engine with a synchronous generator and a computer control system, Ref.[2].

REFERENCES

[1] Ericson, A., The SVIAB Wind Turbine Control System. Symposium and workshop on electrical systems and components for WECS, Hindås, 1984.

[2] Holmblad, L. and Linders, J. A 25 kW autonomous wind-diesel system with transistor convertors and accumulator storage.
Chalmers University of Technology, October 1984.

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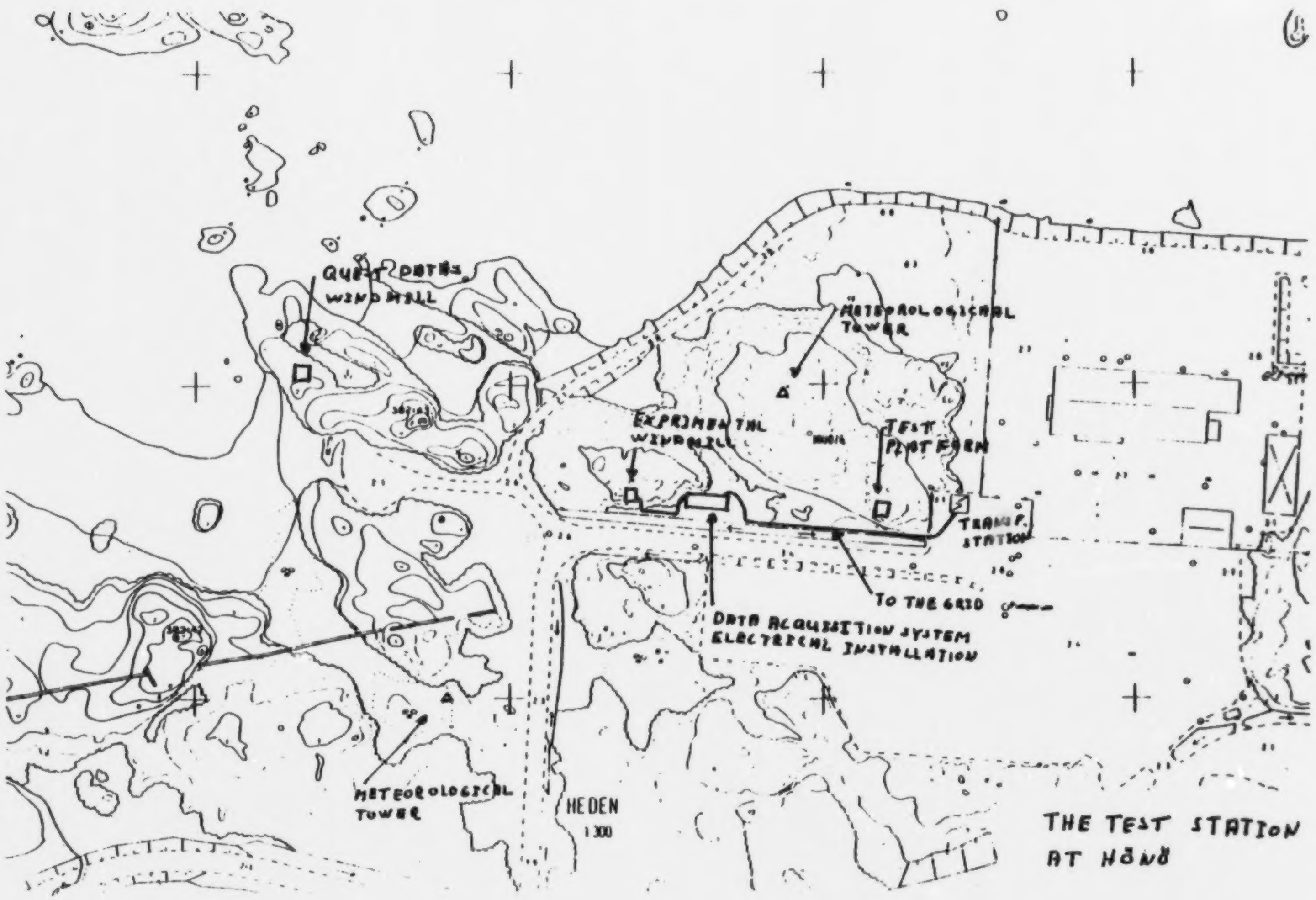
QUIET DATAS WINDMILL
METEOROLOGICAL TOWER
EXPRIMENTAL WINDMILL
TEST PLATFORM
TRANSF. STATION
TO THE GRID
DATA ACQUISITION SYSTEM ELECTRICAL INSTALLATION
METEOROLOGICAL TOWER
HEDEN
1300
20

THE TEST STATION AT HÖNÖ

REPORTS SUBMITTED BY THE DEPARTMENT OF ELECTRICAL MACHINES AND POWER ELECTRONICS IN THE FIELD OF WIND ENERGY CONVERTER SYSTEM.

From 1974 to 1984

DATE:	TITLE:	AUTHOR:
November, 1974	The performance of the Synchronous Flux Generator in a Wind Power Plant.	Svante v Zweygbergk
March, 1976	The performance of the induction generator in a wind power plant. (In Swedish)	Piotr Druzynski A. Gustavsson Lars Johansson
April, 1976	The squirrel-cage induction generator by direct switching-in to the grid. (In Swedish)	Piotr Druzynski
June, 1976	A preliminary classification of duration curves for different alternative generators. (In Swedish)	Piotr Druzynski
August, 1976	The performance of an induction generator intendent for a windmill at three-phased short circuits. (In Swedish)	Piotr Druzynski Jan Erlandsson
January, 1977	Generation of wind power by means of an induction generator. (In Swedish)	Piotr Druzynski
February, 1977	Experiences gained from the operation of two small wind power plants. (Progress report)	
June, 1977	The induction generator in transient state. Induction generators in the power grid.	Piotr Druzynski Abdel-Aty Edris Svante v Zweygbergk
October, 1977	A study of the problems concerning adaption and connection to the utility network of a wind power plant with a squirrel cage induction generator. (In Swedish)	P. Bergström Å. Kinnander
November, 1977	Grid connecting of the wind power unit at Bohus Malmön (In Swedish)	Tore Svensson
1977	The designing of a 1 kVA inverter for a wind power station. (In Swedish)	Tore Svensson
1977	Load matching with seriescapacitors. (In Swedish)	Tore Svensson
1977	Development of a control circuit to maximize power from a wind generator supplying a constant resistor.	Tore Svensson

February, 1978	Transient stability analysis of a wind-driven synchronous generator under step and harmonic wind torques.	Abdel-Aty Edris
March, 1978	Experiences gained from the operation of two small wind power plants. (in Swedish)	Tore Svensson
March and May, 1978	Report concerning measurements of the performance of the asynchronous generator in the wind power plant at Kalkugnen, Sweden.	Hans Johansson
May, 1978	Some methods to control an asynchronous generator of a wind power plant from the statorside.	Lars Gertmar
May, 1978	Shunt-compensation of induction generators.	Piotr Druzynski
June, 1978	Test of a 10 kW Assar-generator compared with other generators. (In Swedish)	Stefan Toader
June, 1978	Switching-in transients in a wind power plant equipped with an induction generator, (1). (In Swedish)	Piotr Druzynski Lars Johansson
June, 1978	Report regarding a study tour to the United States of America, with the purpose to investigate the status of wind and wave energy research.	Svante v Zweygbergk Herman Helgesen (Lund institute of Technology)
September, 1978	Measurements of transient overvoltage at the switching-in of shunt capasitors to the grid.	Piotr Druzynski Hans Johansson Åke Kinnander
September, 1978	Short circuiting of the current-limiting reactors in an asynchronous wind power plant.	Piotr Druzynski
September, 1978	Report about a studying trip to the Unit States.	Abdel-Aty Edris
November, 1978	Random synchronization of a synchronous generator, equipped with a brushless excitation system.	Abdel-Aty Edris
November, 1978	Measurements made at the wind power plant, Kalkugnen during phase compensation with shunt capacitors. (In Swedish)	Hans Johansson
November, 1978	The wind Energy Symposium	
December, 1978	A digital grid connecting unit for an induction generator in a windmill (In Swedish)	Kurt Svensson
1978	Investigation of the Zephyr wind generator. (In Swedish)	Åke Kinnander

January, 1979	Switching-in transients in a wind power plant equipped with an induction generator,(2). (In Swedish)	Piotr Druzynski Lars Johansson
February, 1979	Measurements on the wind power plant with rigid hub in Kalkugnen during october 1977--september 1978.	Svante v Zweygbergk
March, 1979	Preliminary results from measurements on a wind power plant of 15kW,at Habo	Tore Svensson
March, 1979	Transient analysis of a 2,5MVA synchronous generator in a controlled wind electric energy conversion plant.	Abdel-Aty Edris
March and May,1979	Designing a direct driven wind generator. (In Swedish)	Piotr Druzynski Lars Johansson C. Sadarangani
May, 1979	Synchronizing equipment for a grid-connected induction generator in wind power stations. The equipment is micro-computer-based and depend on the speed of rotation and average wind.(In Swedish)	Tomas Unfors
May, 1979	Induction generator performance affected by external resistance-reactance in series with the stator winding.	Abdel-Aty Edris
May, 1979	Micro-computer based equipment for measurements of wind speed distribution, and simulations measurements of the power distribution from a wind mill. (In Swedish)	Tomas Unfors
July, 1979	A preliminary calculation of a direct driven synchronous pancake generator for 25 rpm, 50Hz. (In Swedish)	Piotr Druzynski
March, 1980	Dynamic characteristics of a wind driven induction generator equipped with thyristor controlled inductances on the stator side.	Abdel-Aty Edris
September, 1980	Control of a wind driven induction generator from the stator. "Experimental test" (In Swedish)	Abdel-Aty Edris L.G Hauptmann
October, 1980	Measurements on an induction generator made for a wind power station. (In Swedish)	Jonny Hylander
November, 1980	Measurements made during the synchronizing of an induction generator. (In Swedish)	Abdel-Aty Edris

November, 1980	Test of a low speed Assar-generator made for a wind power station. (In Swedish)	Jonny Hylander
November, 1980	Grid connection measurements of an induction generator with a synchronization unit of the type RASA.	Ola Carlsson Abdel-Aty Edris
February, 1981	Measurements of a Darrieus windmill at Chalmers test station for small windmills. (In Swedish)	Tomas Unfors
April, 1981	Report form the Third International conference on Future Energy Concepts. (In Swedish)	Ola Carlsson
May, 1981	Some methods to connect a wind power induction generator to the untility network.	Ola Carlsson Jonny Hylander
May, 1981	A wind power meter.(In Swedish)	Ulf Andersson Tomas Unfors
June, 1981	Construction of a wind distribution meter.(Dissertation report, In Swedish)	Ulf Andersson Lars Herrnsdorf
August, 1981	Three different methods to connect a wind driven 2,5MW induction generator to the grid.(In Swedish)	Ola Carlsson Jonny Hylander K-E Hallenius
September, 1981	Conference paper on wind energy conversion,Brighton,UK	Ola Carlsson Jonny Hylander
November, 1981	Investigation of the performance of a 22kW windmill induction generator with gears. (In Swedish)	Jonny Hylander
August, 1982	A studying journey to USA and Canada on the summer of 1982.	Jonny Hylander Ola Carlsson
October, 1982	Brushless induction generator with an adjustable powerfactor.(In Swedish)	Svante v Zweygbergk
December, 1982	Some methods for transient analysis of induction machines used for wind generators.(In Swedish)	Svante v Zweygbergk K-E Hallenius Ola Carlsson Jonny Hylander
1982	The influence of the harmonics in rotor current on the wave shape of the stator voltage in a double-fed winddriven induction generator.	Jonny Hylander Ola Carlsson

January, 1983	A report about "The workshop on electrical vonversion system" held at Petten, Holland on the 26th and 27th	Cesar Briozzo Ola Carlson Jonny Hylander
March, 1983	A report about "The fifth Brittish wind energy conference held at Reading, England on the 23rd-25th of March 1983. (In Swedish)	Jan Linders Svante v Zweygbergk
May, 1983	A report about "The Third International meeting of a test stations for SWECS" held at Pellworm, Germany 3th-4th of May 1983. Visiting the large windmills Growian and Monopteros. (In Swedish)	Cesar Briozzo Jan Linders
May, 1983	Energy calculations for a windmill with polechangeble induction generator or two/three coupled induction generators. (In Swedish)	Ola Carlsson
July, 1983	Measurement of a grid connection unit with thyristors intendent for a wind driven induction generator. (In Swedish)	Cesar Briozzo Spiros Tsiolis
September, 1983	A meter for power and number of revolutions from a synchronous generator with rectifier intended for battery charging. (In Swedish)	Robert Eriksson Cesar Briozzo
September, 1983	Evaluation of the SVIAB 065 wind energy conversion system for battery charging.	Cesar Briozzo Spiros Tsiolis
October, 1983	Preformance of a non grid connected 12,5kW wind power plant at Habo.	Jonny Hylander
October, 1983	Construction and manufacture of a wind direction meter. (In Swedish)	Robert Eriksson
December, 1983	Investigation of the properties of the autosynchronous generator as a wind generator. (In Swedish)	Cesar Briozzo Ramón Gutiérrez Svante v Zweygbergk
December, 1983	Investigations of various methods to reduce torque peaks in a wind power plant with an induction generator.	Jonny Hylander
January, 1984	Investigation of a model of an autonomous wind-diesel system. (In Swedish)	Lars Holmblad Jan Linders
March, 1984	Investigation of a method to control the output from a wind power induction generator by using a pulse cintrolled resistance connected to the rotor circuit.	Svante v Zweygbergk Ola Carlson Robert Karlsson

March, 1984	Proceedings of the Symposium and Workshop on Electrical Systems and Components for Wind Energy Converter Systems, Hindås, Sweden.	Jan Linders
March, 1984	Transient analysis of the self excited asynchronous generator.	Karl-Erik Hallenius
March, 1984	Investigation of a model of an autonomous wind-diesel system.	Lars Holmblad Jan Linders
March, 1984	Activities on the wind energy field at Chalmers University of Technology.	Svante v Zweygbergk
March, 1984	Grid-connecting using thyristors: The SVIAB wind turbine control system.	Cesar Briozzo Anders Ericson
March, 1984	The Chalmers wind mill for experimental purposes.	Cesar Briozzo G.M. van den Broek
May, 1984	Report from the 4th International Meeting of test station of S.W.E.C.S, in Trébeurden, Franc, May 23-24, 1984. (In Swedish)	Cesar Briozzo Spiros Tsiolis Svante v Zweygbergk
August, 1984	An autonomous wind-diesel system without energy storage.(In Swedish)	Lars Holmblad
September, 1984	Investigation of steady state operation of a wind power induction generator with an external resistance connected to the rotor circuit.(In Swedish)	Ola Carlson
October, 1984	Two-speed Asynchronous Generators and their Caracteristics in Wind Power Plants. Part 1. (In Swedish)	Svante v Zweygbergk
October, 1984	A 25 KW autonomous wind-diesel system with transistor convertors and accumulator storage. A progress report.	Lars Holmblad Jan Linders
October, 1984	The autosynchronous machine as a wind generator.(Degree project, in Swedish)	Ramon Gutierrez
November, 1984	Transient model of an induction generator with power electronics connected to the rotor circuit to create variable speed operation. (In Swedish)	Jonny Hylander

The Rutherford Appleton Laboratory (RAL) Wind Test Site

E Bossanyi

I. Introduction

RAL is run by the UK Science and Engineering Research Council, a government-funded body which supports research by universities and polytechnics in science and engineering. The Council itself allocates grants to researchers in universities and polytechnics, while its laboratories, such as RAL, assist researchers by providing central facilities and resources which the different institutions can make use of. RAL was originally set up around a particle accelerator for fundamental physics research, but has since diversified into other areas such as space physics, lasers, electronics and computing.

The Energy Research Group (ERG) at RAL is a small group of about 10 people, including two temporary research associates and two visiting university research fellows. At present the group's activities are almost entirely concerned with wind energy. It has three main roles: research support, co-ordination, and actual research. Before describing the test site operated by the group, these three functions are briefly reviewed.

1. Research Support

In keeping with the original purpose of the lab, the ERG provides support for university researchers in a number of ways, by maintaining certain central resources, both hardware and software.

(a) hardware: the lab (through ERG) operates a small wind turbine test site which is used by a number of researchers; it will be described in more detail below. As well as the wind turbines, this includes anemometry, instrumentation and data logging equipment as well as technical, design and workshop effort.

(b) software: all university researchers (not just in wind energy) can gain access to the central computers at RAL where ERG maintains several databases containing for example a large amount of meteorological data as well as electricity demand data both for the national grid and for certain small communities. The meteorological data includes many station-years of hourly wind speed data as well as some 1-minute and 2-second data. Some of the computer programs developed by researchers associated with ERG can also be made available to other researchers via the computer network - one example is the large grid system simulation model developed originally at Reading University to study the effects of large-scale wind energy input to the national grid, which has since been used by researchers at Cambridge University and also in the Netherlands.

2. Co-ordination

The ERG does what it can to try and ensure that a reasonably coherent programme of university research in wind energy evolves in the UK, by engaging in discussion with other researchers and organising occasional meetings to bring different institutions together. Of course there is already close contact with those institutions involved in collaborative projects with RAL. In addition, ERG can give advice on the writing of research proposals, and attempts to ensure that proposals submitted by different institutions to SERC for funding appear to be reasonably co-ordinated.

3. Research at RAL

Much of the research carried out by ERG is done in collaborative projects between RAL, universities and industry. In addition some individual research is carried out by ERG members, sometimes with funding from outside bodies such as the Department of Energy or the CEC. An outline of the main research projects will be given. Some of them involve the hardware on the test site, while others are more theoretical or software-orientated, and in some cases use hardware situated elsewhere.

II. The RAL Test Site

At present the test site contains three wind turbines, two 20m mobile meteorological masts and a number of smaller ones, various anemometers and wind vanes, a diesel generator and a programmable load for wind/diesel experiments, and various data logging systems including two HP85 micros. The general layout of the site is shown (approximately) in Figure 1.

The prevailing SW wind blows over fairly smooth rolling downland with a few trees and hedges. From other directions the flow is disturbed by the laboratory buildings and is often very turbulent. The site has a rather low mean wind speed and would therefore be inappropriate for any thorough testing of commercial wind turbines, but it is adequate for the sort of research experiments normally carried out at the site. As can be seen from the following account, the three different turbines are being used for very different types of experiment:

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(a) The 6m "Musgrove" VAWT : this novel variable-geometry straight-bladed VAWT was developed by Musgrove at Reading University [1] and since its installation it has been used by a number of different researchers for various experiments. Its performance and blade forces were measured in 2 and 3-bladed configurations by Stacey and Musgrove [2] and both fibreglass and aluminium rotors have been used, giving different structural behaviour [3]. Fig 2 shows the use of a novel binning system devised by Bossanyi and Stacey for producing a power coefficient curve from experimental measurements with large wind speed errors [4]. At the present time, the turbine is being instrumented with numerous pressure transducers by Garside of Cranfield Institute of Technology, in order to make detailed measurements of the unsteady aerodynamic effects encountered with such machines [5].

(b) The Northwind 9m HAWT : this 16 kW turbine was purchased by Hawker Siddeley Power Plant, a UK diesel generator manufacturer, as part of a collaborative research programme between themselves, RAL and Imperial College of London on wind/diesel systems [6]. The aim is to develop a workable hybrid power plant for stand-alone operation. HSPP have also provided the 7 kW diesel generator for these experiments, while a computer-programmable resistive load, built by RAL, simulates the electricity demand of a small community. An initial series of tests was conducted by Jenkins to determine the power curve with the turbine connected to the grid: Fig 3 shows the advantage of using a boom-mounted anemometer just upstream of the (downwind) rotor, provided a blockage correction is made. Parallel operation with the diesel has been achieved successfully. In order to make more significant fuel savings it is necessary to be able to turn off the diesel altogether when it is not required. In order to maintain system reliability some form of energy storage is then required; the firm of Laing has recently joined the collaboration and is supplying a flywheel to be incorporated into the system. Initially the flywheel will be allowed to vary only between the acceptable frequency limits of the system, but eventually it is planned to couple it to a variable speed induction motor/generator under development by Smith at Leicester University. This will result in increased storage capacity by allowing the flywheel speed to vary between zero and twice synchronous.

(c) The Imperial College 8m HAWT : this machine is about to be commissioned with a smaller (3.4m) rotor for initial testing. It was developed at Imperial College and has a novel hub design with the blades mounted on universal joints to allow free coming and full pitch contol. After a series of performance and dynamical tests it is planned to use it as a test bed for a new single phase induction generator developed at Imperial College and also for the Leicester University variable-speed system mentioned above. This will be done with the full-size rotor, which is to be strain-gauged at a number of positions to allow a series of measurements designed to investigate radial flows and post-stall aerodynamics, in a proposed collaborative project with the Central Electricity Generating Board.

III Other Research

A brief review follows of the other main areas of research related to wind energy in which members of the ERG are involved. Only selected references are given.

a) Integration of wind energy into the National Grid - fuel savings, control strategies, economics, penetration limits, etc, (with G Whittle, Reading University): formal project completed, [7,8] but still some ongoing work e.g. on effects of improved wind predictions.

b) Impact of energy storage on the national grid [9].

c) Modelling of small wind/diesel systems [10].

d) Collaboration with Reading University on their wind turbine simulator, used to study battery and hydraulic storage [11,12]

e) Stochastic short-term prediction and its application to optimal control strategies, including wind/diesel systems [13].

f) Collaborative study with Strathclyde University and the North of Scotland Hydro Electric Board to investigate major applications of wind power in Shetland, a group of islands with a 30 MW diesel grid. This involves surveys of two hill-top sites using 45 m fixed meteorological masts, instrumented at 8 levels to record high-speed data, and detailed simulation modelling of the grid system.

IV References

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[2] Stacey G and Musgrove P J, "Blade and Tower Forces on Vertical Axis Wind Turbines and Field Measurements compared with Theoretical Predictions", proc. European Wind Energy Conference, Hamburg, 1984 (CEC).

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[4] Stacey G and Musgrove P J, "The Performance of the Rutherford 6m Diameter Vertical Axis Wind Turbine, Including the Effects of Various Binning Techniques and Averaging Periods", proc. 6th BWEA Wind Energy Conference, Reading, 1984 (CUP).

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[12] Slack G and Musgrove P J, "Hydraulic Accumulator Storage for use in Wind/diesel Generating Systems", proc. 7th BWEA Wind Energy Conference, Oxford 1985 (MEP).

[13] Bossanyi E A, "Short-term Stochastic Wind Prediction and Possible Control Applications", proc. Delphi Workshop on Wind Energy Applications, Delphi, 1985 (EWEA/CEC).

FIG. 1: PLAN OF RAL TEST SITE (Approximate)

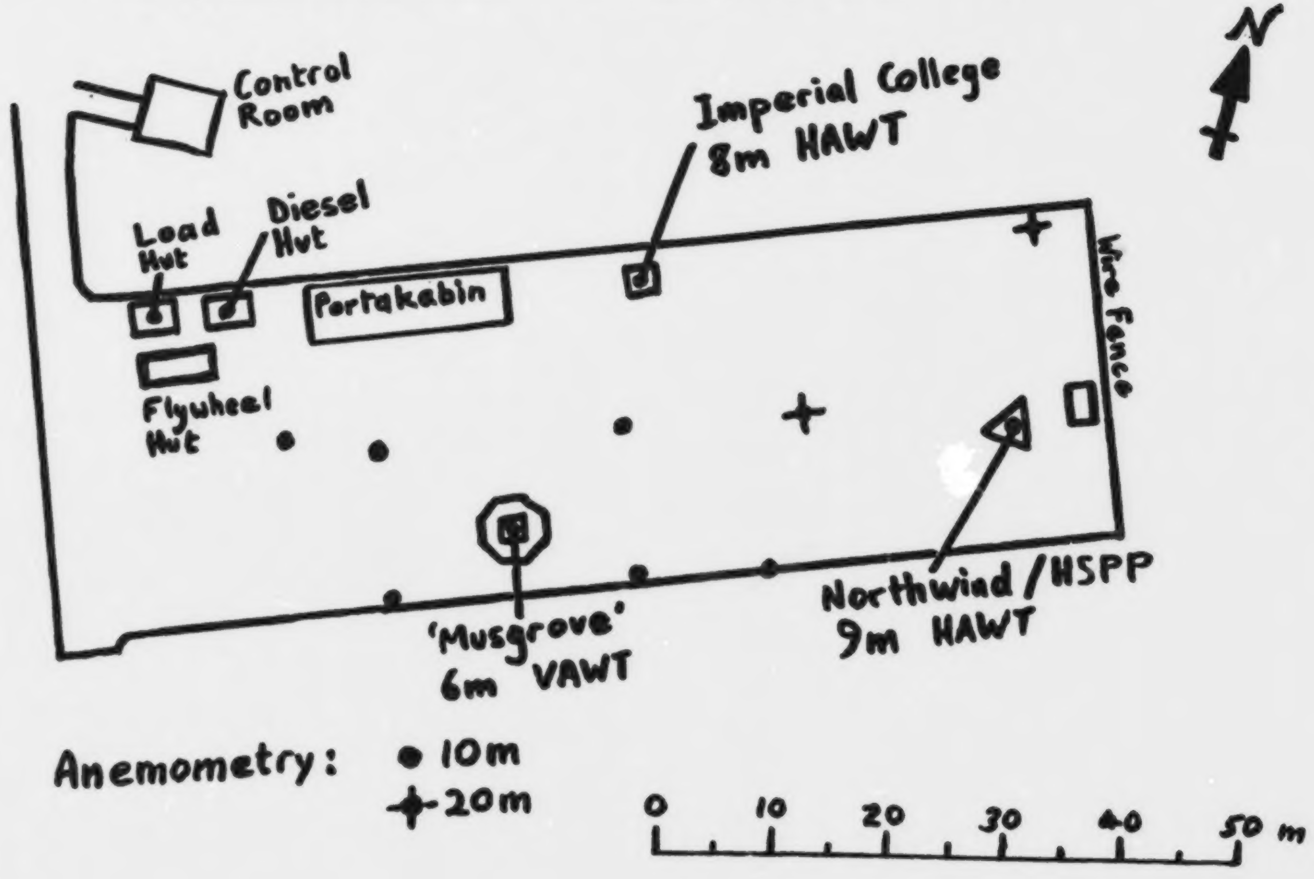
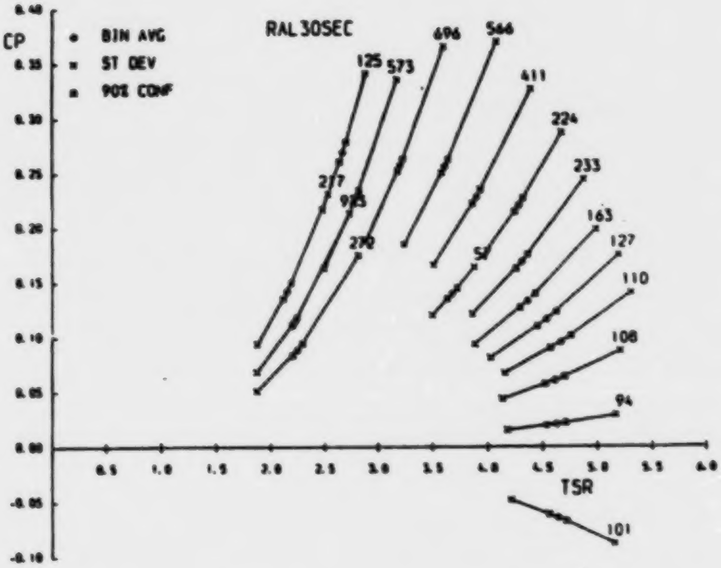

N
Control Room
Imperial College 8m HAWT
Load Hut
Diesel Hut
Portakabin
Flywheel Hut
Wire Fence
'Musgrove' 6m VAWT
Northwind / HSPP 9m HAWT
Anemometry:
● 10m
✚ 20m
0
10
20
30
40
50 m

Fig. 2 Power coefficient versus tip speed ratio using cubic bins: 30 second averaging.



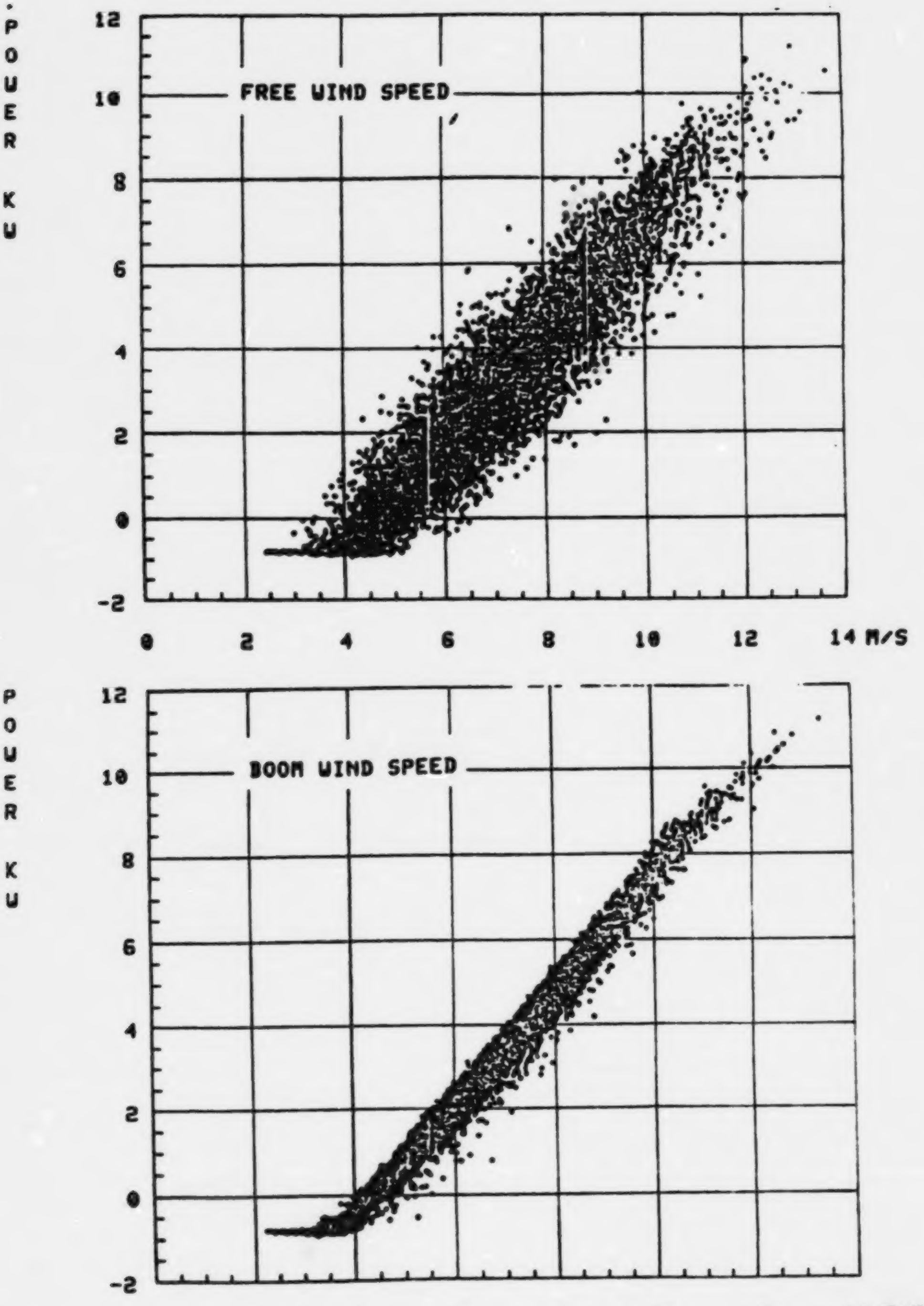


FIG 3: Power Curve Measurement of Northwind Turbine - 30-sec. averages

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1 INTRODUCTION

In May 1984 the National Engineering Laboratory (NEL) obtained financial support and approval from the Department of Trade and Industry (DTI) and the Scottish Development Agency (SDA) to set up and operate a test centre for commercial wind turbines. At present most of these fall into the small to medium range, with rated outputs up to 100 kW. This paper describes the facilities of the test centre.

The support from the DTI is intended to cover staffing costs for three years, by which time, if continued support is to be justified, the manufacturing industry must clearly have demonstrated significant sales and growth for both the home and overseas markets. In addition, manufacturing industry will have to demonstrate the continuing need for a test centre through its commercial utilisation.

NEL intended to work in conjunction with other organisations that have expertise on wind turbines, and related technology, to develop engineering knowledge and to work towards the creation of standards covering quality, design, safety and operation. Work on standards will recognise the needs of British manufacturers but compatibility with European, US and IEA Standards will be sought.

The main objectives of the National Wind Turbine Centre (NWTC) are to provide technical assistance to UK companies wishing to become established in the manufacture of wind turbines and to promote UK companies seeking to enter the home and overseas markets. This assistance will include:

a independent accreditation of a machine's performance and reliability,

b the provision of engineering and technical expertise to improve the design and cost effectiveness of machines, and

c the promotion of reliability by assuring high standards of material selection, design and quality of manufacture.

The NWTC will have access to the whole range of mechanical engineering expertise already available at NEL especially in the fields of power transmission systems, materials and structural testing, control systems engineering and metrology.

It is intended that the NWTC test site will be used for both short-term tests of a wind turbine's performance as well as long-term evaluation of performance and reliability.

2 THE TEST SITE

The site was chosen for the following reasons.

a Clean wind conditions over a wide range will allow all operating modes to be tested.

b The location within the Scottish industrial belt ensures convenient access by road, rail and air (Fig 1).

c The direct line of sight to NEL will allow the use of a high capacity data link using microwave radio transmission into a real-time data analysis system.

d The proximity to NEL will facilitate use of the technical and manpower resources of the main laboratory.

e The site is large enough to accommodate a number of turbines to share the capital outlay and running costs.

f There is an import and export connection with the national grid providing readily available operating conditions for appropriate machines.

The site is located at Myres Hill, Eaglesham, approximately 9 km south west of NEL at East Kilbride and 16 km from Glasgow. It covers an area of 7 hectares and will be enclosed by a 1.8 m high security fence.

Investigation of available meteorological office data relevant to the site shows a great deal of consistency in the wind distribution diagram. The occurrence for a given direction is shown in Fig 2. Analysis of this data determined the optimum orientation of the test site on a line 22.5 degrees west of north.

The site is situated on a high moorland plateau 330 m above sea level with a clear uninterrupted outlook on all sides. The terrain gradually slopes to the south west towards the Firth of Clyde, 48 km away, and there is also a gradual slope to the east.

Examination of local meteorological data shows that the average annual wind speed is expected to be in excess of 6 m/s, and wind speeds in excess of 50 m/s are likely to be experienced on two or more occasions annually.

The site is being constructed in two phases. Phase 1 should be commissioned in spring 1985 and Phase 2 will proceed at a future date if the growth in demand warrants expansion.

The test site is shown in Fig 3. Phase 1 consists of three universal pads capable of accepting a variety of machine designs, including both horizontal and vertical axis types and tower designs. Also, if required, there is ample space between the main pads and the rear of the site to locate additional test pads, for small machines such as battery charging turbines and water pumps. In addition a further three universal pads of around the 100 kW size are planned for Phase 2, to the south of the existing site.

Each foundation pad, shown in Fig 4, consists of an elaborate arrangement of holding down bolts cast in a square 8.25 m reinforced concrete base in order to accommodate different tower designs. There are 384 fixing bolts, per pad, these being 30 mm diameter mild steel with an overall length of 900 mm. A 150 × 150 × 20 mm thick plate is welded to the base of each bolt. The length of bolt cast into the concrete is approximately 775 mm, leaving a threaded length of 125 mm protruding above the concrete level. The universal foundations have been designed, using the site design wind speed of 60 m/s, to withstand a nominal overturning moment of 2500 kN m and a sliding force of 180 kN. Larger machines than those envisaged could be accommodated on these foundations, if required, subject to satisfactory foundation loading calculations being carried out for each individual design.

A meteorological tower of 50 m nominal height is situated at the northern end of the site. This tower is used to mount the meteorological instrumentation which consists of seven sets of wind speed and wind direction transducers mounted at various intervals, along with two air temperature transducers at 5 and 30 m above ground level. The anemometers will be used to provided the vertical wind profile and long-term wind statistic of the site.

In addition a microwave antennae system, consisting of transmitting and control receiving antennae, is mounted on the main meteorological mast to transmit the data from the wind turbines to NEL for analysis. This will also receive signals in order to carry out remote calibration checks.

Associated with each universal pad is a trailer-mounted anemometer mast which will be positioned at hub height immediately up-wind of each machine under test. The masts have a height of 21 m, which is sufficient for the wide range of machines likely to be tested.

Adjoining each wind turbine pad is a small cabin which houses the local instrumentation, together with the power metering and control units for the particular wind turbine under test. The main instrumentation and control centre for the site will be located within two accommodation units at the northern end. A detailed account of the instrumentation within these buildings is described later in the paper under the section dealing with the data acquisition system. During the commissioning of individual turbines, NEL staff will be in attendance daily, however once machines and the site are fully operational it is intended that the site will operate unmanned.

Provision has been made for the power from the various aerogenerators to be either exported to the national grid or dissipated locally via resistive loads.

A 45 000-litre water reservoir is provided for testing water pumping machines and as coolant for direct heat generating machines.

A universal test pad, identical to those pads on the test site exists within the grounds of NEL at East Kilbride if required.

The wind regime at NEL is more benign than at the test site and this test pad will be used by NEL and manufacturers' staff, to study particular design and operational aspects in more detail, before subjecting machines to the more rigorous environment at the main test site at Myres Hill.

The two main systems on site are the data acquisition system and the power control and collection system. A third system, the remote control, allowing shutdown, calibration checks etc, will be introduced at a later date.

3 DATA ACQUISITION AND ANALYSIS SYSTEM

Data is collected from the wind turbine test pads and the meteorological towers. In general the measurements are sampled and digitally encoded before being sent as a serial data stream, over fibre-optic links, to the test site control room. At the site control room some of the data is processed before being remerged at intervals with the on-line data stream, where it is then transmitted over a microwave radio link to NEL for immediate analysis, collation and archiving. This system is shown as a block diagram in Fig 5.

Data is collected on the following topics:

a Wind regime at the test site.

b Wind conditions at each wind turbine.

c Power performance.

d Safety features, ie the effectiveness of power take-off control, braking and shutdown operations.

e Condition monitoring, such as cyclic stressing.

f Quality of electrical output during all stages of operation.

g Acoustic noise.

The performance of the data acquisition system will more than meet the accuracies and sampling rates given in the current IEA recommended practices for testing and evaluation of wind turbines. These are summarised in Table 1.

When considering the sampling rate, the overriding criterion is that storage or processing equipment should be able to accept data at the chosen sampling rate. The analysis system at the NEL control centre can cope with 61 channels at 13 Hz sampling rate, plus one channel at 833 Hz, and one 16-bit digital channel. In practical terms a sampling rate of at least five times the desired signal bandwidth is recommended for spectral analysis, but this does not apply to signals for fatigue analysis. For fatigue evaluation a sampling frequency of about 10 times the signal bandwidth is required to specify the peak amplitude of a signal with 95 per cent confidence. To deal with these higher frequency signals an analysis system capable of handling 10 channels at 100 Hz will be installed at the site, and this is shown in block form in Fig 6.

It has been decided to take meteorological measurements at the following nominal positions:

a Wind speed and direction at the meteorological tower at the heights of 5, 10, 15, 20, 25, 35 and 50 m, with scope for repositioning in specific cases.

These measurements are taken using cup-type anemometers with distance constants of 5 m.

b The wind vector at the meteorological tower at a height of 20 m using three axis propeller type anemometers.

c Air temperatures at the meteorological mast at heights of 5 and 30 m.

The instrumentation for the transducers on the non-rotating parts of the test pad and turbine is housed in small cabins at each test pad. The block diagram of this internal data collection at the test site is shown in Fig 7. Instrumentation consists of excitation and signal conditioning, using four pole Butterworth filters with 20 Hz bandwidth (sample rate 100 Hz/channel), followed by a multiplexer and encoder to convert the data to PCM (pulse code modulation) format. This data is also combined with digital data, such as status flags, eg a flag to indicate when the wind turbine is connected to its dump load. This data system is based on a 12-bit analogue-to-digital convertor, giving a resolution of 0.025 per cent of the full dynamic range of the input signals. Each data channel, within the group of 16, has its own source address so that the data plus address forms a 16-bit word. Thus the channel address can be used to isolate and extract any channel from the data stream either for inputting to a microprocessor or for conversion back to analogue form.

The PCM data as obtained above is then sent in serial format over a fibre-optic link to the site office. The use of a fibre-optic link reduces signal corruption due to cross-talk or electrical pickup, and it also helps minimise the risk of injury or damage to equipment due to a possible lightning strike, the test site being on a hill top location.

The data from rotating sources is dealt with in a similar way. However the use of a data acquisition system for transducers on the rotating parts of wind turbines is not always practicable since instrumentation etc require to be mounted on the rotor. This gives rise to the problem that power has to be provided to the rotating parts of the machine for transducers and instrumentation, and invariably little space is available for these purposes, eg shaft space for slip rings.

Perhaps future standard recommendations should include the provision of space for measurements on rotating parts as an essential part of any accreditation procedure.

At the site office the data is handled in one or more of the following three ways.

a All variables are made available in analogue form and may be monitored, along with visual observation of the turbine in order to get a 'feel' for any turbine behaviour which is of interest.

b Appropriate variables are preprocessed at the site office, eg stress histories are analysed in the form of frequencies of stress cycles. These stresses may require to be sampled at a rate which is too high for the radio link. Fortunately this sort of analysis can be done using low cost microprocessors. These is also a dedicated system to provide a long-term record of wind speeds and directions measured at the meteorological tower.

c Signals coming from the wind turbines with a bandwidth compatible with the microwave radio telemetry link, are immediately transmitted along with the preprocessed data to the NEL control centre.

The processed data is sampled at intervals and sent via the digital channel. At present there are 30 analogue channels available from each wind turbine test pad and 16 from the meteorological tower. The microwave telemetry link cannot cope with all of the data channels at the test site, and selected channels are connected in groups of eight to suit requirements. However in general the channel allocations are shared between each of the test pads and the meteorological tower.

The serial data stream on reception at the NEL control centre is decoded and converted to parallel format, using direct memory access it is put into a dual computer system for immediate analysis in terms of basic statistical parameters, and selected channels are subjected to fuller analysis. The supervisory computer is a DEC 11/23 minicomputer with 248 Kbytes of main memory, and mass storage of 10 Mbytes hard disc plus twin floppies. The fast processing computer is a Plessey Miproc. The block diagram for the test site to NEL acquisition telemetry and storage system is shown in Fig 8, and the NEL analysis system in Fig 9.

All raw data is stored in PCM form on magnetic tape for backup storage in the event of a computer malfunction, or for possible reanalysis.

The PCM data is formatted for the microwave telemetry link in compliance with the DIN 66 224 standard for telemetry and magnetic recording. This standard is more restricted than the wider ranging IRIG standards, but is more specifically suited to data acquisition systems, particularly in encouraging compatibility between records from different sources.

4 POWER CONTROL AND COLLECTION SYSTEM

Each pad can take machines of up to 100 kW rating. However it is possible to alter the power system to accommodate turbines of up to 300 kW if connected to the grid.

Initially only induction generators will be allowed to be connected to the grid, as they cease to generate when the excitation is removed, thus avoiding the possibility of feeding a 'dead' supply line and injuring an unsuspecting linesman. However, at a later stage it is hoped that a suitable arrangment for connecting synchronous machines to the grid via a synchronous link convertor, can be agreed with the South of Scotland Electricity Board (SSEB). This should be acceptable, since a synchronous link like an induction generator ceases to operate when disconnected from the grid.

Synchronous generators will usually be connected to individual resistive load dumps appropriate to their output. The load regulator for these dump loads may optimise on power throughput or simulate a grid connection.

Water pumping machines are able to be accommodated with the provision of a 45 000-litre reservoir on site. This reservoir would also be used for machines intended for direct heat production.

5 THE FUTURE

Discussions are taking place with other research organisations in UK, Europe and overseas with regard to future R & D and standards work, and it is possible that some scope for UK university research activity will be established in parallel with NEL's commercial interests on the test site. NEL looks forward to an active involvement by the manufacturing industry and centres of research to further wind turbine technology in the UK and to promote a profitable industry.

6 ACKNOWLEDGEMENT

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Table 1

Variable	Test	Accuracy % FS	Sampling rate Hz	Sampling interval	Important parameter
Electrical power	Quality	3	1	10 minutes	
Reactive power	Quality	3		10 minutes average	
Wind speed	Quality	5			
Generator current	Quality	2	Continuous	At event	
Voltage waveform	Quality, harmonics		2-2.4 kHz	7 minutes	
Rotor speed (N)	Several	1	N		
Wind speed	Fatigue	5			Distance const. = [illegible]
Wind direction	Fatigue	5°	5		
Blade azimuth	Fatigue	10°	4 × speed		
Blade pitch	Fatigue	1	4 × speed		
Blade bending moment	Fatigue	5	10 × speed × blade frequency		
Shaft torque	Fatigue	10	10 × torsion frequency		
Tower stresses	Fatigue	5	10 × bending frequency		
Wind speed	Power	5(4-25 m/s)			Distance const. < 5 m
Wind direction	Power	5		10 minutes average	
Pressure and temperature	Power	1		10 minutes average	
Electrical power	Power	3		10 minutes average	

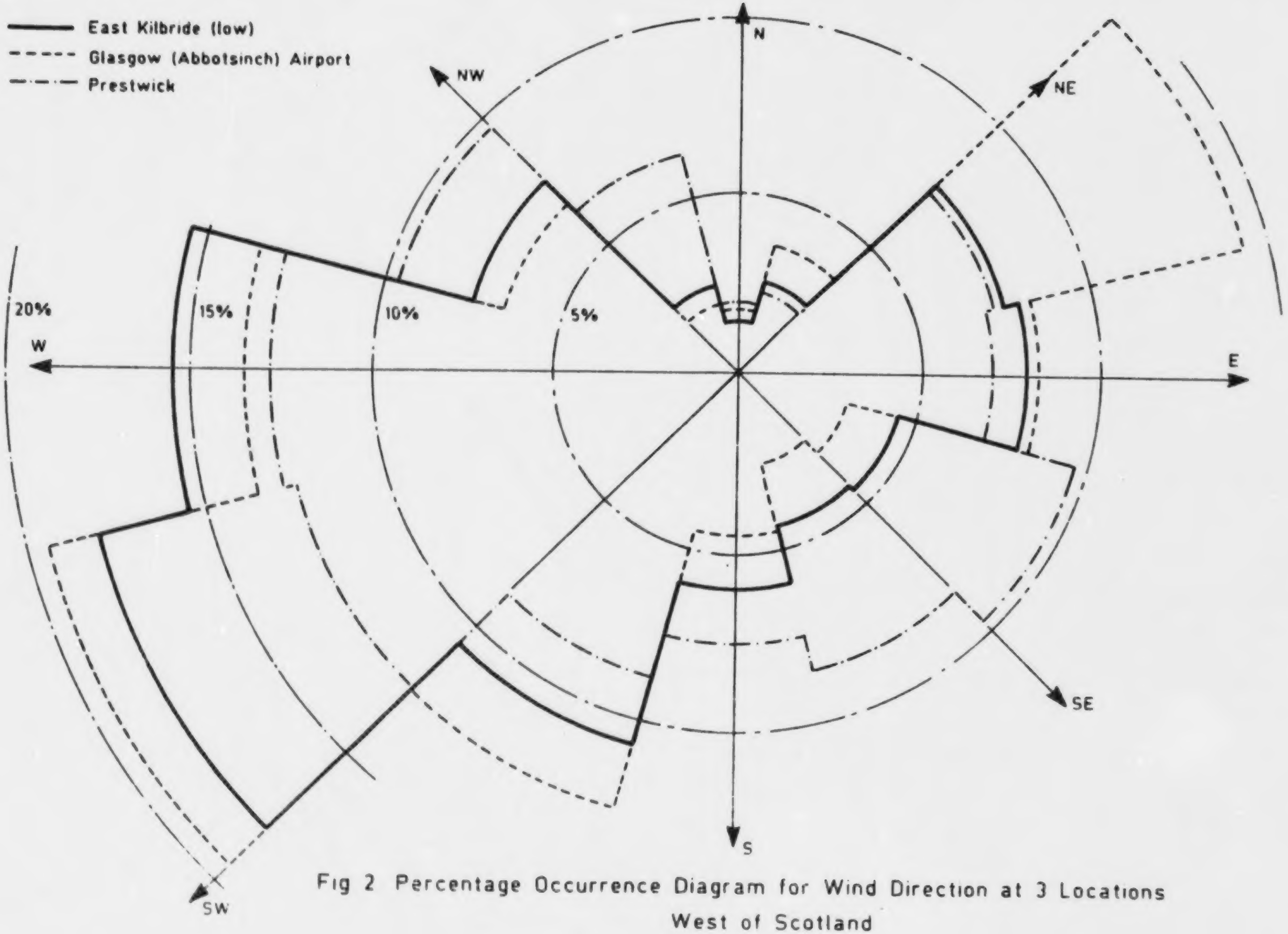

Fig 2 Percentage Occurrence Diagram for Wind Direction at 3 Locations West of Scotland

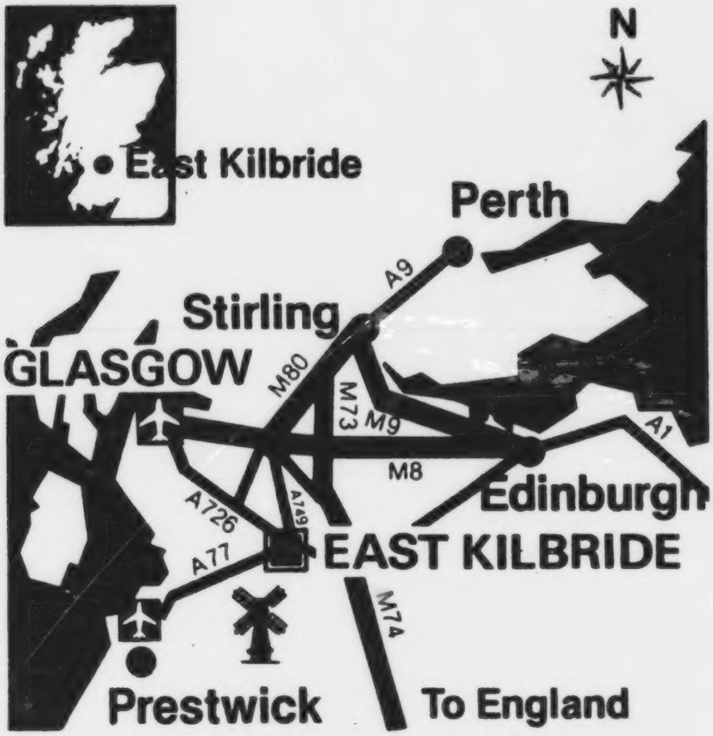
N
East Kilbride
Perth
A9
Stirling
GLASGOW
M80
M73
M9
A1
M8
Edinburgh
A726
A749
A77
EAST KILBRIDE
M74
Prestwick
To England

FIG 1. LOCATION OF TEST SITE

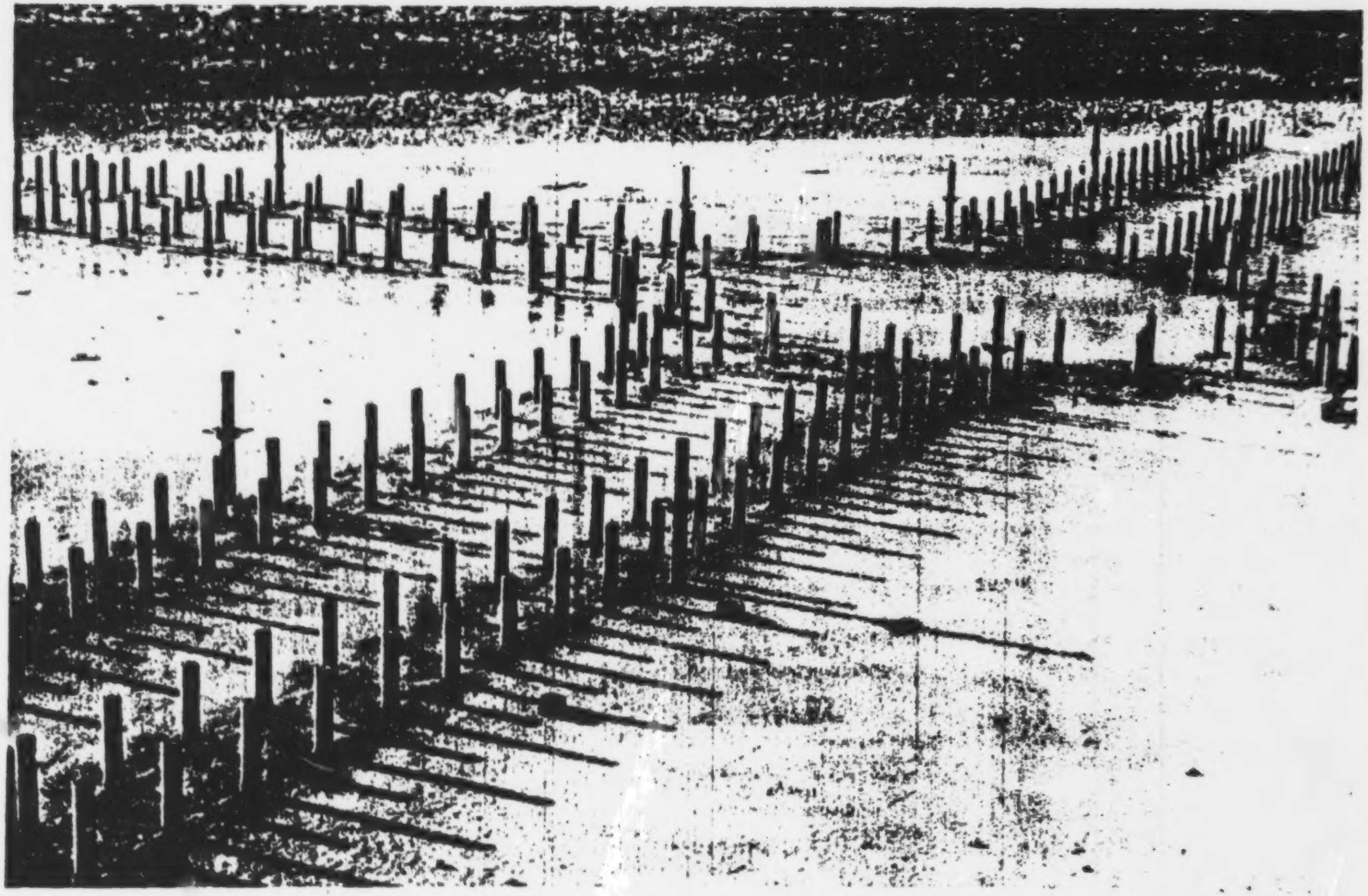

FIG.4 UNIVERSAL FOUNDATION PAD

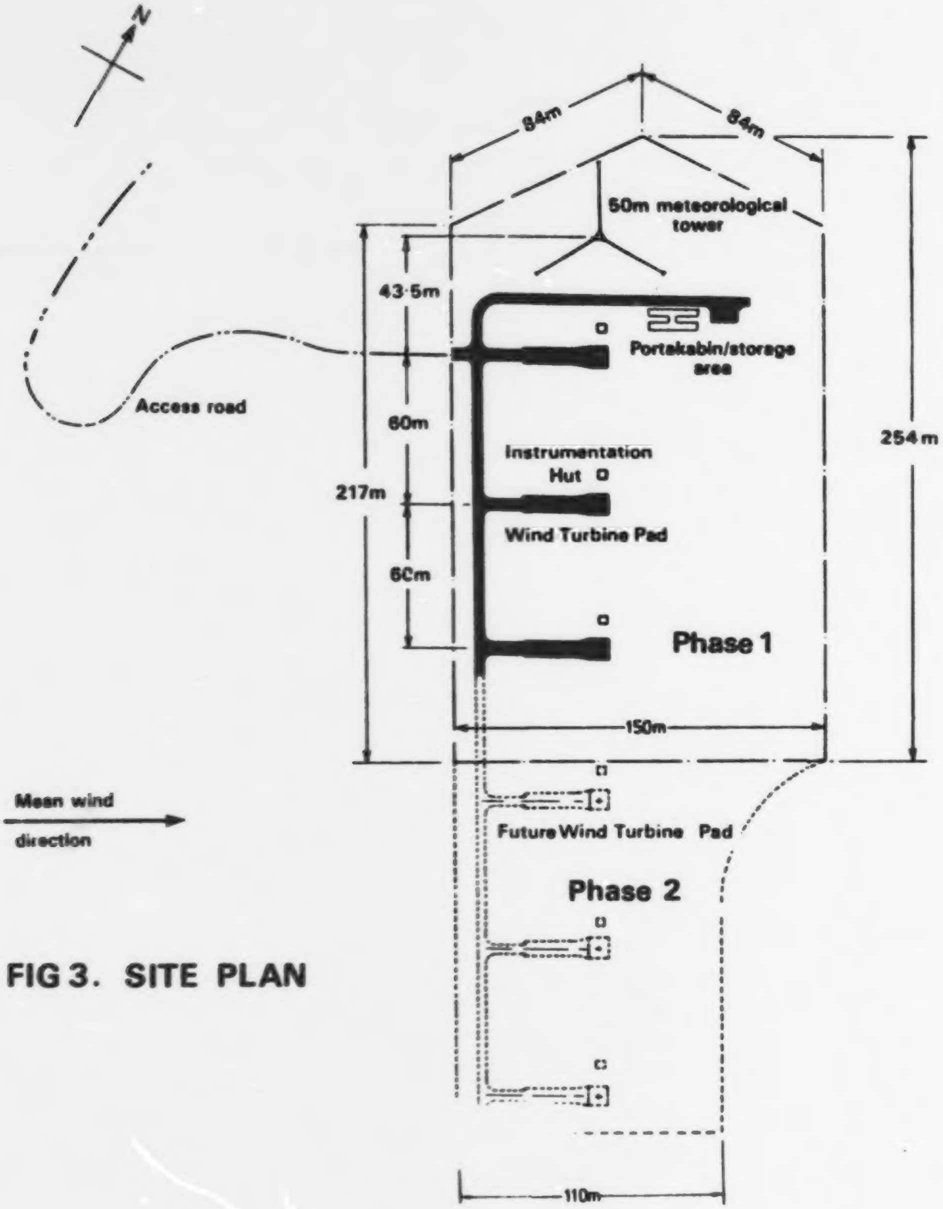
N
84m
84m
50m meteorological tower
43·5m
Portakabin/storage area
Access road
60m
Instrumentation Hut
217m
254m
Wind Turbine Pad
60m
Phase 1
150m
Mean wind direction
Future Wind Turbine Pad
Phase 2
110m

FIG 3. SITE PLAN

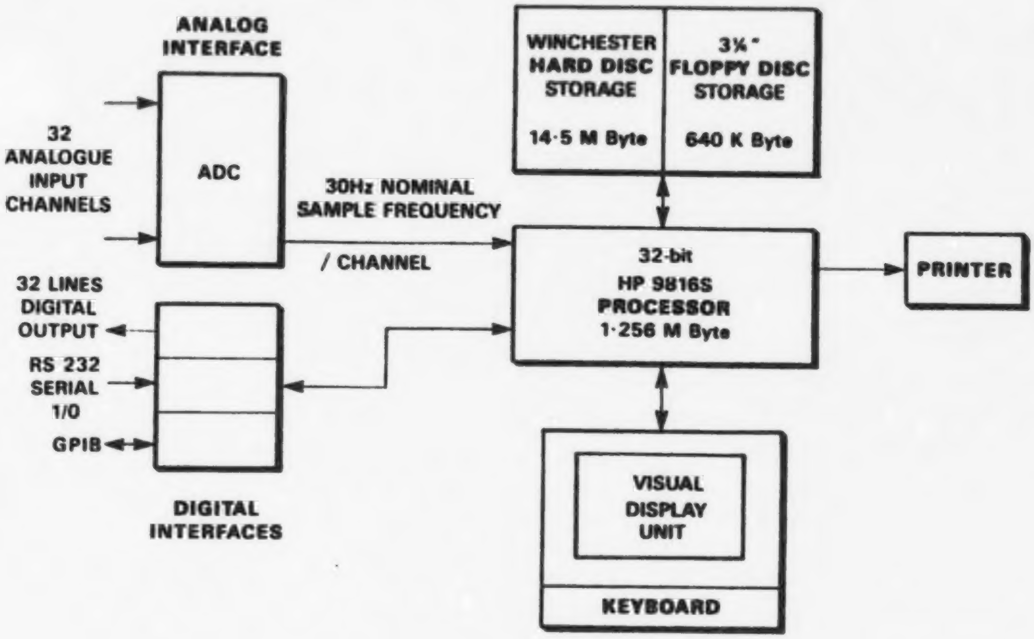
ANALOG INTERFACE
32 ANALOGUE INPUT CHANNELS
ADC
30Hz NOMINAL SAMPLE FREQUENCY / CHANNEL
WINCHESTER HARD DISC STORAGE
14·5 M Byte
3¼" FLOPPY DISC STORAGE
640 K Byte
32-bit HP 9816S PROCESSOR 1·256 M Byte
PRINTER
32 LINES DIGITAL OUTPUT
RS 232 SERIAL 1/0
GPIB
DIGITAL INTERFACES
VISUAL DISPLAY UNIT
KEYBOARD

FIG. 6 ON SITE LOGGING AND ANALYSIS PACKAGE

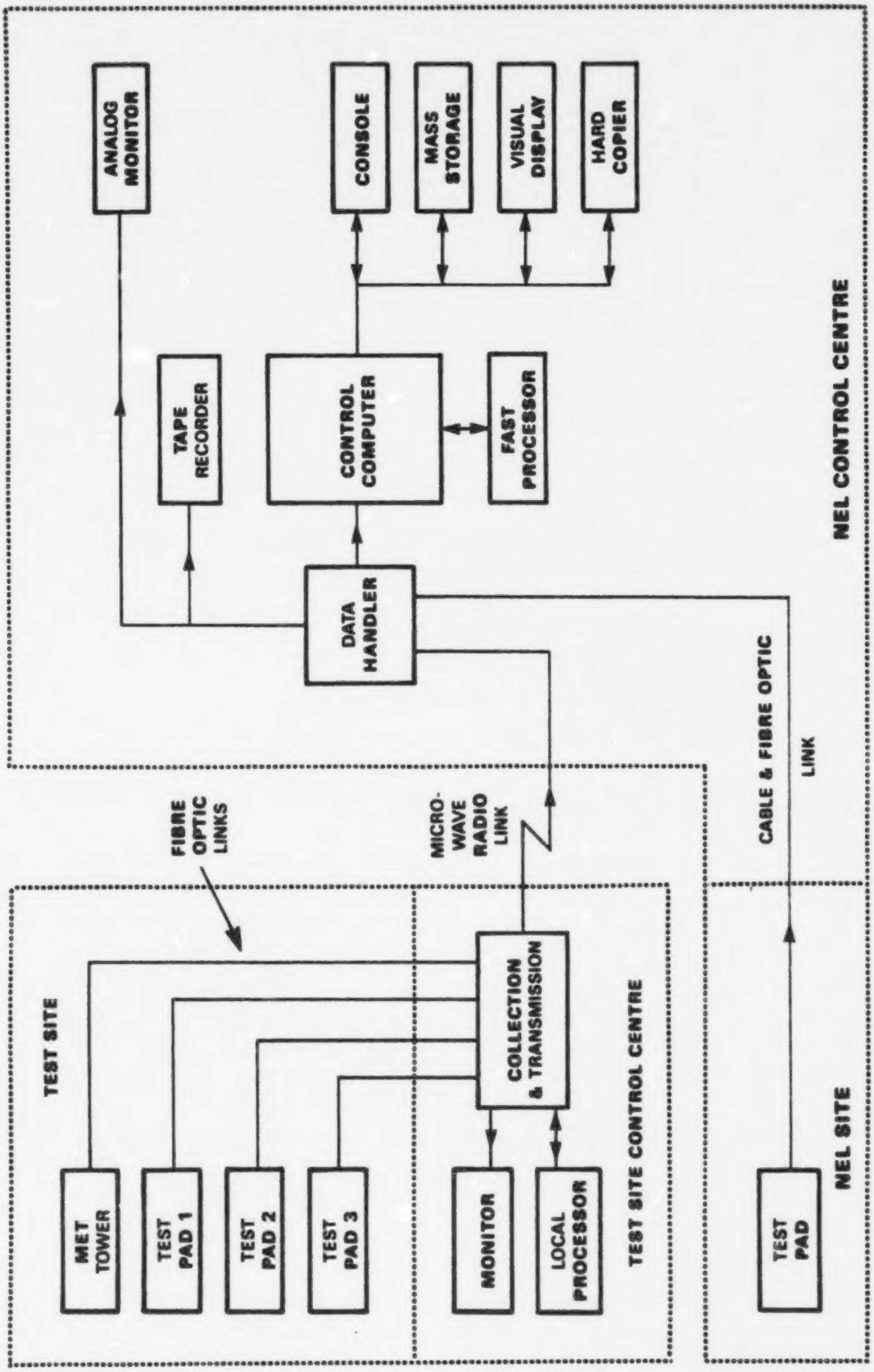
TEST SITE
MET TOWER
TEST PAD 1
TEST PAD 2
TEST PAD 3
FIBRE OPTIC LINKS
COLLECTION & TRANSMISSION
MONITOR
LOCAL PROCESSOR
TEST SITE CONTROL CENTRE
MICRO-WAVE RADIO LINK
DATA HANDLER
TAPE RECORDER
ANALOG MONITOR
CONTROL COMPUTER
FAST PROCESSOR
CONSOLE
MASS STORAGE
VISUAL DISPLAY
HARD COPIER
NEL CONTROL CENTRE
CABLE & FIBRE OPTIC LINK
TEST PAD
NEL SITE

FIG 5. WIND TURBINE DATA ACQUISITION & ANALYSIS

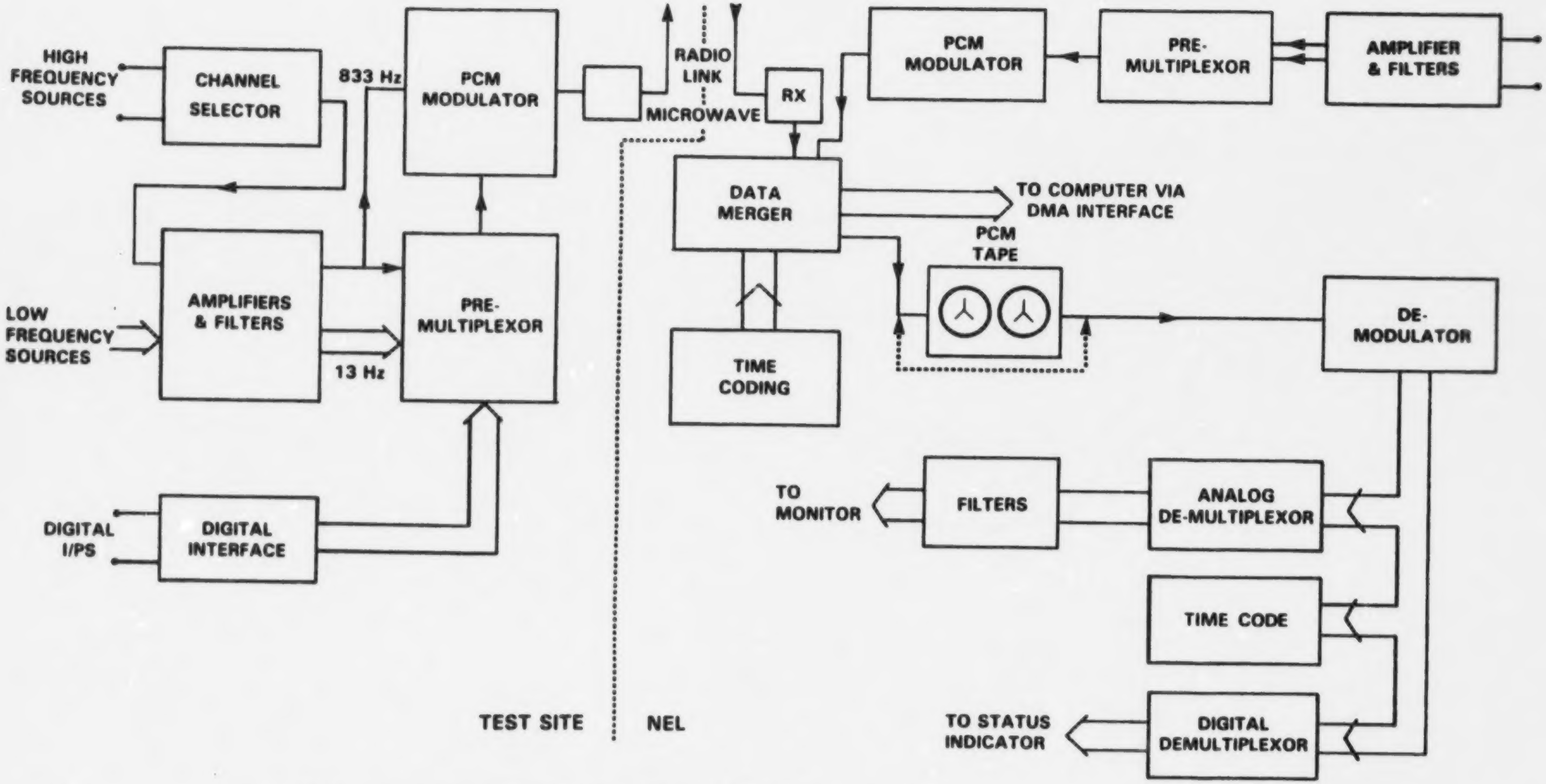
HIGH FREQUENCY SOURCES
CHANNEL SELECTOR
833 Hz
PCM MODULATOR
LOW FREQUENCY SOURCES
AMPLIFIERS & FILTERS
13 Hz
PRE-MULTIPLEXOR
DIGITAL I/PS
DIGITAL INTERFACE
RADIO LINK
MICROWAVE
RX
PCM MODULATOR
PRE-MULTIPLEXOR
AMPLIFIER & FILTERS
DATA MERGER
TO COMPUTER VIA DMA INTERFACE
PCM TAPE
TIME CODING
DE-MODULATOR
TO MONITOR
FILTERS
ANALOG DE-MULTIPLEXOR
TIME CODE
TO STATUS INDICATOR
DIGITAL DEMULTIPLEXOR
TEST SITE
NEL

FIG. 8. TELEMETRY LINK FROM TEST SITE TO NEL

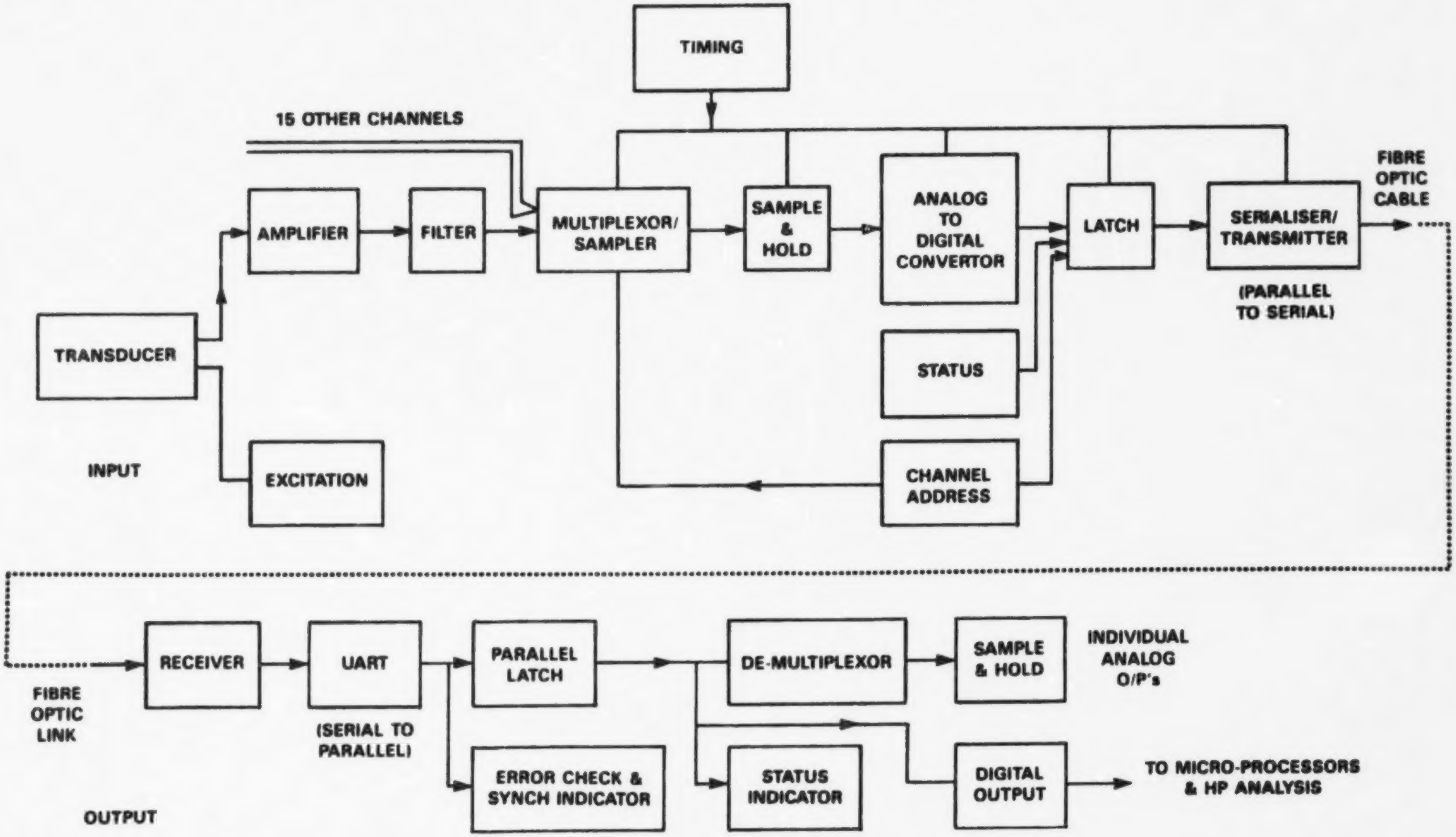
TIMING
15 OTHER CHANNELS
TRANSDUCER
AMPLIFIER
FILTER
MULTIPLEXOR/ SAMPLER
SAMPLE & HOLD
ANALOG TO DIGITAL CONVERTOR
LATCH
SERIALISER/ TRANSMITTER
FIBRE OPTIC CABLE
(PARALLEL TO SERIAL)
STATUS
CHANNEL ADDRESS
INPUT
EXCITATION
RECEIVER
UART
PARALLEL LATCH
DE-MULTIPLEXOR
SAMPLE & HOLD
INDIVIDUAL ANALOG O/P's
FIBRE OPTIC LINK
(SERIAL TO PARALLEL)
ERROR CHECK & SYNCH INDICATOR
STATUS INDICATOR
DIGITAL OUTPUT
TO MICRO-PROCESSORS & HP ANALYSIS
OUTPUT

FIG. 7. TEST SITE INTERNAL DATA COLLECTION (ONE FOR EACH 16 CHANNEL)

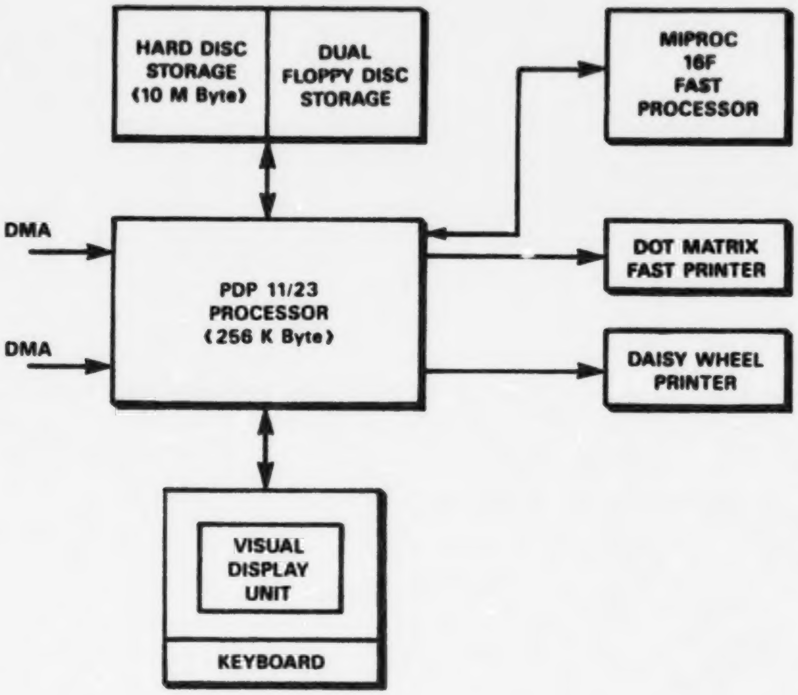
HARD DISC STORAGE (10 M Byte)
DUAL FLOPPY DISC STORAGE
MIPROC 16F FAST PROCESSOR
DMA
DMA
PDP 11/23 PROCESSOR (256 K Byte)
DOT MATRIX FAST PRINTER
DAISY WHEEL PRINTER
VISUAL DISPLAY UNIT
KEYBOARD

FIG. 9. NEL ANALYSIS AND ARCHIVING SYSTEM

WIND ENERGY PROGRAM, AEI AND ARS

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Canyon, TX 79016

INTRODUCTION

The program of the Alternative Energy Institute (AEI) includes: 1) Data collection, research and feasibility studies. 2) Development and testing of alternative energy systems. 3) Collection and distribution of information. 4) Education of students and others through research, courses, seminars, and workshops. Primary emphasis has been placed on wind energy although information and an introductory course on solar energy are available.

The Conservation and Production Laboratory, Agricultural Research Service (ARS) had a program to evaluate agricultural applications of wind energy. The program direction has been changed to evaluation of wind turbines for irrigation pumping.

WIND CHARACTERISTICS

AEI has an ongoing program of data collection from 10 stations across the Northwest part of Texas and 1 station along the coast. The program consists of compiling windspeed histograms for day and night at heights of 20 m and 50 m. The data are not continuous, but the preliminary results indicate more power at 50 m than that would be calculated from lower heights (Table 1) as there is less diurnal variation at 50 m. As present stations are discontinued, new stations will be located along the coast and in the Guadalupe Mountains near El Paso.

EDUCATION AND INFORMATION

AEI is the main source of wind information in Texas. ARS is a primary source of information on agricultural applications in the U.S. AEI also receives a number of requests at the national level. An introductory workshop on wind energy has been given at regional and international meetings. A list of manufacturers and a notebook of brochures of wind turbine manufactures are available from AEI.

An introductory course on wind energy and wind turbines is offered every other year and AEI is planning a short course on installation and maintenance of wind turbines. International researchers have visited AEI for periods from days up to 5 months. Quite a bit of information on wind energy in Latin America has been collected. Personnel from AEI also consult on wind energy in the U.S. and overseas.

EVALUATION OF WIND TURBINES

AEI and ARS have a cooperative program to evaluate agricultural applications of wind turbines. The ARS program uses wind turbines that are commercially available. The DAF 40 was used for irrigation pumping in parallel with an electric motor and later in parallel with a diesel engine(1,2). The Windworker 10 was used as an electric to electric stand-alone system for pumping water(3). The DOE (17 m VAWT), Carter 25s, and Enertech 44s were used as wind assist systems for pumping irrigation water(4,5). The systems that were connected to the grid have operated a number of hours(Table 2). Although the DAF 4 is not the most suitable wind turbine, it is being used in a stand alone system for low lift pumping(6).

The DAF 40 has been dismantled and the DOE VAWT is to be dismantled after 10,000 connect hours. The two Carter 25s at the Canyon Well Field have been taken down.

An earlier project of a field test of a horizontal axis unit with power at ground level for pumping irrigation water failed because of the problems with a prototype wind turbine at a distant location(7). Much of the same type of problems were encountered with the UTRC on a project to assist in stripper well pumping(8). Therefore AEI decided to consolidate its program of testing of wind turbines to a location near the campus of the University.

AEI WIND TEST CENTER

The Wind Test Center (WTC) location of 100 acres has space for 10 to 12 WECS. A 240 V distribution system, 150 kw capacity and four pads were installed in 1983. A 480 V distribution system, 200 kw capacity, was installed in 1984. At present 4 units are being operated, the PM is being dismantled and the low cost Enertech 44/60 is to be installed in September 85.

The most important factor is annual energy output. Six to eight months of operation time is recommended or until the unit has produced at least half of the manufacturer's predicted annual energy. Utility meters measure the energy produced and consumed by the wind turbines. Running time and windspeed histograms are the other data collected on a continuous basis. Operational time is very important because it provides the mechanism for finding problems in components. Power curves are obtained with the data acquistion systems.

Other aspects being investigated are power variation with pitch angle, surface roughness of blades, and tip brakes. Power can vary significantly with different pitch angles(9). For the Enertech 44/25, a 1 degree pitch changed the power output by 6 kw. Presently the pitch angle is being varied by 30 minute steps on the Enertech 21/5 (Fig. 1). The removal of the tip brakes improved the performance at the design pitch, 3 degrees. Enertech has increased the coning angle for the 21/5 to improve the yaw, as the unit consumed 2.7 kw when it ran upwind, average windspeed of 5.2 m/s.

Surface roughness on laminar airfoils can also significantly affect the power output. Sandpaper, 40 grit, on the leading edge of the blade of the Carter 25 reduced the power by 75% and fine sand reduced the power by 25%. Bug buildup on the Enertech 44/60 blades reduced the peak power output from 60 to 35 kw. Similar results have been noted by manufacturers and wind farmers. For example, a wind farmer reported that the bug buildup on the Enertech 44/40 reduced peak power from 40 to 25 kw.

All of the prototypes and first production models have had a number of modifications(10,11). The PM was designed for 25 kw rated with a peak power of 31 kw at 120 rpm. The blades were to progressively stall and limit the rpm to 180 during loss of power and brake failure. The unit actually produced a maximum of 54 kw. Therefore a stall strip was employed to reduced the power output. Slight changes in the position, 0.5 cm, of the stall strip changed the peak power output (Fig. 2).

INSTRUMENTATION

The main data acquisition systems at the Wind Test Center and ARS are PDP 11s. The sample rate and averaging time for data recorded on disk are variable. Generally the sample rate is 4 hz and the averaging time is 1 to 10 seconds at the WTC and 15 seconds at ARS.

Both AEI and ARS have Campbell Scientific CR21 microcomputer data loggers, which are self contained, battery powered. The sample rate on the CR21 is 0.1 hz with the windspeed averaged over the 10 seconds. The sample rate on the CR21X is 1 hz. Data from acquisition systems are transfered to main frame computers for analysis.

At the WTC, met tower data (3 levels of windspeed and 1 wind direction) are logged into windspeed bins by a Natural Power Compilator, which is read once a month. A second compilator with 1 anemometer is read once a week.

SUMMARY

ARS has shifted the emphasis of their program to evaluation of wind energy for irrigation. Manufacturers can have their wind turbines tested at the AEI Wind Test Center. Those manufacturers which have sold a large number of wind turbines do not need such a service. Others generally do not have the capital for the needed testing, although every prototype has problems and too many units have been put on the market without adequate testing.

The aerodynamic effects of surface roughness, pitch angle for fixed pitch units, stall strips, and flaps need to be investigated at the basic research level and in field tests. Airfoils need to be designed specifically for wind turbines and then tested under atmospheric conditions. The airfoils should be insensitive to surface roughness and have a broad lift curve so as to reduce peak loadings.

Table 1. Average windspeed and average power density.

Location	Windspeed, m/s			Power, watts/sq m		
	10	20	50	10	20	50
Dalhart	4.9	6.1	7.2	170	260	300
Amarillo	5.5		7.8	202		430
Perryton	5.9	6.6	7.9	214	283	423
Muleshoe (in town)	4.1		5.8	96		218
10 km southwest		6.8	7.9		309	450
Childress	4.5	5.1	6.5	125	153	277
Lovington, NM	5.1	5.9	7.7	157	216	414
Stanton	4.6	5.8	7.0	122	153	295
Abilene			5.6			193
Wichita Falls	3.9	4.9	6.2	78	128	228
Fort Worth		4.8	6.1		128	239

Table 2. Energy output of wind turbines connected to the grid. Connect is the time generator is energized.

Unit	Dates	Energy kwh	Availability %	Connect hours
DOE 17 m	4/83-12/84	274520	54	9820
Carter, #1	8/79- 8/84	141111	73	23359
	8/83- 8/84	36401	97	6145
	1/85- 6/85	9820	83	1667
Carter, #10	3/81- 6/83	60910	76	7080
Carter, #11	3/81- 6/83	71070	74	8212
Enertech 21/5	11/83- 6/85	10040	97	7450
Enertech 44/25	7/82- 1/84	97485	95	8925
Enertech 44/40	4/84-10/84	49476	99	3218
Enertech 44/60	12/84- 6/85	61222	97	2912
Dakota	5/78-12/80	6380		
Hummingbird	11/83- 6/85	6562		
PM	11/83- 4/85	9750		1390
UTRC	8/81-10/84	27012	65	5500
	1/85- 6/85	5900		

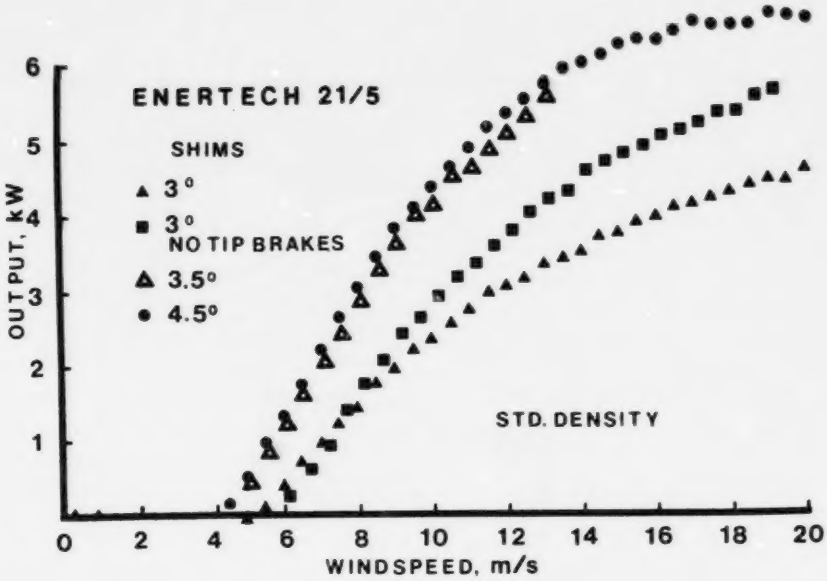

Figure 1. Power curves for Enertech 21/5 at different pitch angles.

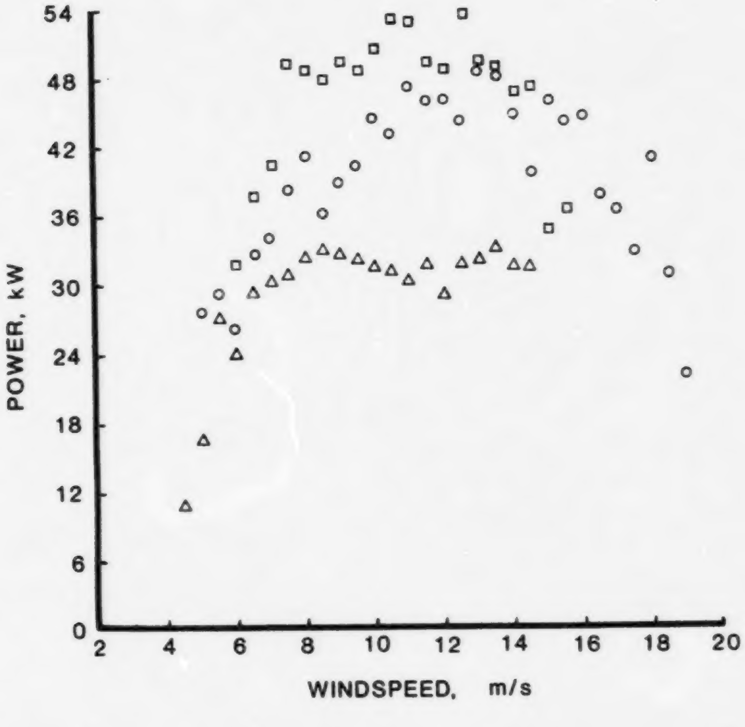

Figure 2. Maximum power for PM, 1 second average. No stall strip (□), stall strip 1.5 cm toward lifting surface (Δ), stall strip 0.7 cm toward pressure surface (o). Data corrected to standard density.

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BIENNIAL SUMMARY
SEPTEMBER 1981—AUGUST 1983

by
Vaughn Nelson

Report 84-1
Alternative Energy Institute
West Texas State University

January 1984

▪ SUMMARY

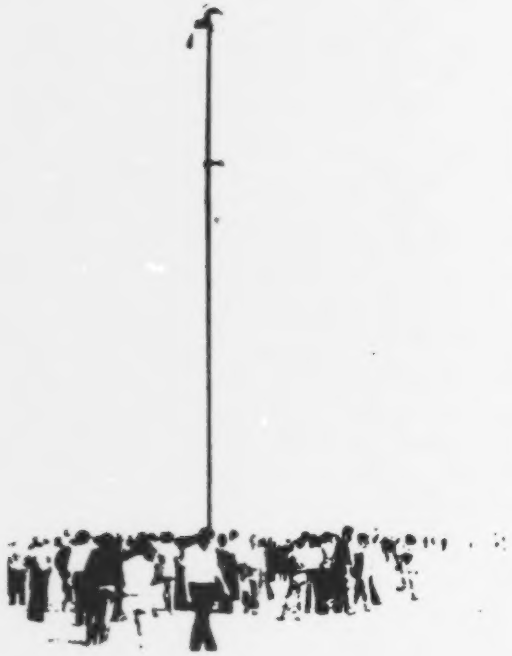
The Alternative Energy Institute continued its program of evaluation of wind energy conversion systems, measurement of windspeeds, education and information. The establishment of the Wind Test Center adjacent to the campus was the most important accomplishment during the period. AEI now has the facilities for testing wind turbines for manufacturers and two units were installed by the end of August 1983. Space is available for 10 to 12 wind turbines.

The cooperative agreement with the US Department of Agriculture, which began in 1976, continues to be beneficial to both groups. Four new wind turbines (PM Wind Power, Humingbird, Enertech 44/25, and Windworker 10) plus seven other wind turbines were evaluated. Two more wind turbines were not run during the period. Main results of the evaluation program are: Operating time is needed to obtain information on reliability and maintenance. Small changes in the rotor, such as blade pitch, can make large changes in power output and annual energy production.

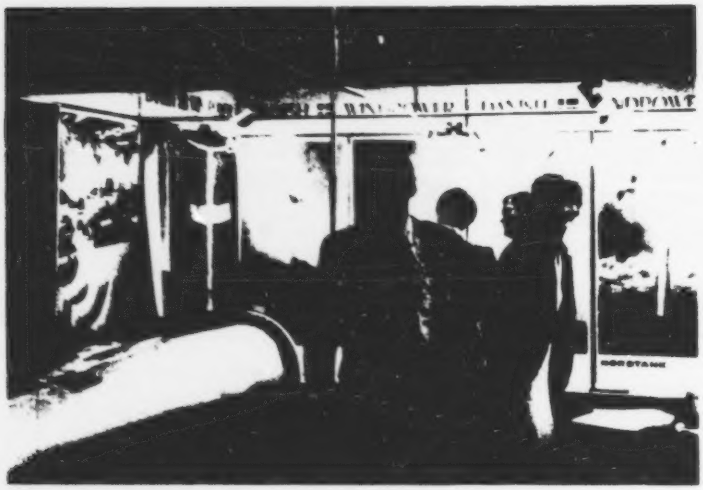
The wind measurement program is now in the fourth year, and within another two years, a good data base will be established for companies interested in wind farms and installation of large wind turbines. The results of the program is that the amount of energy available at hub heights of large wind turbines is larger than that predicted from data taken at National Weather Service stations.

Personnel from AEI have given 20 local and regional presentations, four seminars and four presentations at the national level, and 10 presentations at the international level. AEI is the main source in Texas for information on wind energy as 500 requests are answered each year. Over 3000 pamplets, brochures, and reports have been sent to technical people and the public.

AEI and USDA hosted Wind Energy Expo '82 and National Conference of the American Wind Energy Association. Three hundred participants and speakers, along with 30 exhibitors, attended the exposition and conference. The highlight of the conference was the tour to view the operating wind turbines at the USDA Wind Energy Laboratory.



Wind Energy Expo '82 and National Conference



■ INTRODUCTION

The Alternative Energy Institute (AEI) was created at West Texas State University as an outgrowth of wind energy research begun in 1970. In 1976, AEI entered into a cooperative agreement with the USDA, Conservation and Production Laboratory, Bushland, TX to investigate the use of wind energy for agricultural applications. The cooperative agreement has been beneficial to both parties.

The program of AEI includes:

1. Data collection, research, and feasibility studies.
2. Development and testing of alternative energy systems.
3. Collection and distribution of information.
4. Education of students and others through reserch, seminars, and courses.

Primary emphasis has been placed on wind energy although information and courses on solar energy are available.

■ EDUCATION AND INFORMATION

AEI is the main source of wind information in Texas. Each year the Institute receives over 500 written and telephone requests for information. Visitors are welcome at the AEI Wind Test Center and the USDA Wind Laboratory to see the operating units. Many of our visitors are international and they stay one to three days, however Dr. Kamal Nathan, National University of Singapore spent three months at AEI learning about the practical applications of wind energy.

During the two year period, AEI distributed 3000 copies of Brief Discussion of Wind Energy in Texas, 1500 copies of System Evaluation, and 1000 copies of Guide to Wind Energy in Texas. A Newsletter of 500 copies is mailed twice a year to persons interested in wind energy.

AEI has computer programs for predicting aerodynamic performance of horizontal and vertical axis wind turbines. Individuals and companies in Texas have used this service and copies have been sent to others. Programs on predicting energy output of small WECS from power curves and windspeed histograms are used in economic analysis.

REGIONAL

AEI personnel have given 20 presentations to local and regional groups on wind energy. Among these were a presentation by Dr. Gilmore at the 30th annual Kansas Gas Compression Institute and a presentation by Dr. Nelson at a Wind Energy Forum for the City of Abilene.

NATIONAL

AEI and USDA hosted Wind Energy Expo '82 and National Conference in Amarillo, October 15-19, 1982 for the American Wind Energy Association. Thirty exhibitors, which included the Danish Windpower Manufacturers Association, came to this first exhibition of AWEA along with 300 speakers and participants. One of the highlights was the tour to view the wind turbines at USDA. Dr. Nelson was given an award by AWEA for organizing their National Conferences, primarily for hosting two conferences in Amarillo and organizing the agenda at another. Drs. Gilmore and Nelson presented a half-day introductory seminar to 70 participants on the first day of the conference.

Drs. Gilmore and Nelson presented two half-day workshops on Wind Energy and Wind Turbines at the National Conference of the American Solar Energy Society in Houston. Dr. Nelson was an invited speaker at Wind Workshop V, Washington, DC and at the Renewable Energy Institute Symposium in Anaheim, CA. Ken Starcher presented a paper on the Wind Test Center at the Sixth Biennial Wind Workshop in Minneapolis, MN.

The results from a survey in 1982 by Dr. Nelson, "The State of the SWECS Industry in the US" has been quoted extensively. The report states by the end of 1982 the installed capacity of wind turbines was around 70 megawatts and projected capacity was expected to double in 1983.

INTERNATIONAL

Dr. Nelson spent part of his university development leave studying wind energy in Latin America. He gave six presentations on "AEI/USDA Projects" and "Wind Turbines in the US" to groups in Mexico, Ecuador, Peru, and Argentina. Later he presented two papers at the Conferencia Mundial del Sistemas in Venezuela and did some consulting on wind energy assistance in Jamaica. While in Jamaica he gave presentations on wind energy at the University of West Indies and the Ministry of Mining and Energy.

▪WIND CHARACTERISTICS

The data collection program from 10 stations (Fig. 1) across the Northwest section of the State will provide a data base of wind energy potential for wind farms and large wind turbines which would be connected to the utility grid. This research program is important since Texas has a large wind energy potential and land for wind farms is physically and financially available.

The wind farm boom began in California in 1982 and has continued in 1983 because of their state tax credits and the higher avoided costs paid by utility companies for electricity fed back into the line. By the end of 1983 an estimated 4000 wind turbines were installed with a rated capacity around 250 megawatts. At $2,000/killowatt, the value of those wind turbines is around 500 million dollars. Large wind farms are now planned for Hawaii, Montana, and New York.

Our program consists of compiling windspeed histograms for day and night at heights of 20 and 50 m. The heights were changed from 10 to 20 m during the period as the 20 m height would be around hub height for smaller WECS. Some of the compilators are divided into eight time periods per day.

Results indicate that at 50 m there is a greater average windpower than would be predicted from data taken at 10 m at National Weather Service Stations. This is mainly due to the difference in diurnal windspeeds close to the ground, which is lower at night. Wind data are also being collected at 3 and 5 different heights on met towers at Wind Test Center and at USDA, so wind shear is being measured experimentally. A compilator for windspeed histograms is located at the UTRC site in Borger, TX.

As part of the wind characteristics program, a wind tunnel was built for calibration of anemometers and compilators. Students have been in charge of this part of the program.

▪WIND TEST CENTER

AEI is in the process of consolidating its program of system evaluation of wind turbines at the Wind Test Center adjacent to the campus of West Texas State University. A history of wide spread locations made it difficult to keep track of the wind turbines, except for those monitored by USDA at Bushland. Collection of accurate, reliable data and system monitoring could not be satisfactorily achieved due to lack of manpower and the amount of travel time.

The first site chosen in 1982 was east of the campus. An electrical distribution station was installed for five wind turbines (total output up to 150 kw) along with two foundations. The PM wind turbine was installed at the site. After the nearby highway was blocked because of loss of control of the rotor when a gearbox failed, the Wind Test Center was moved to a location north of the campus.

The present location of approximately 100 acres has room for 10 to 12 wind turbines. The distribution system was also moved and four foundations with electrical connections were installed. The PM and the Hummingbird were then erected at the site. The units are monitored to measure energy production of the WECS and predicted energy from power curves. Power curves are obtained with a data acquisition system (PDP 11/V03) which can be set to a maximum sampling rate of 10 hz.

Other data collected are 4 windspeeds (3 anemometers are on 30 m met tower), direction, pressure, and temperature. The energy in the wind is calculated from windspeed histograms recorded by eight periods per day.

AEI is evaluating wind turbines for manufacturers at the Wind Test Center. The most important factor is operation time and energetics, as this gives information on reliability, maintenance, components, and availability of wind turbines. Manufacturers who are interested should contact AEI.

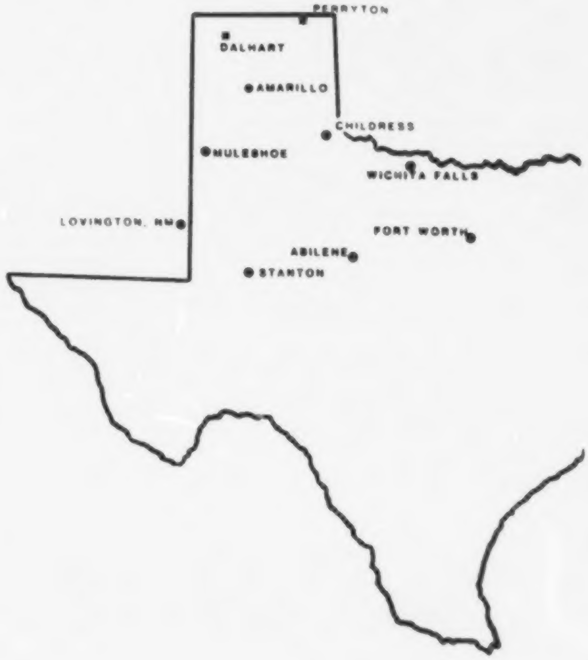


Figure 1. Location of Wind Monitoring Stations and Wind Turbines

■SYSTEM EVALUATION

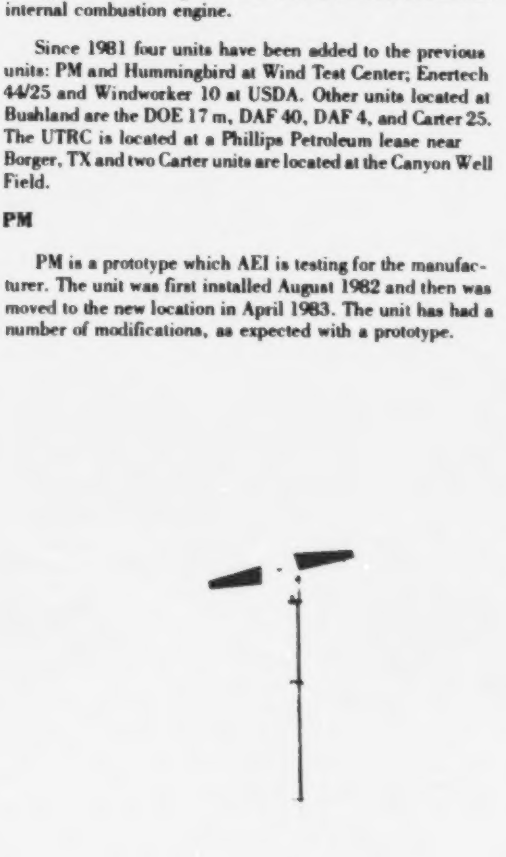
AEI and USDA have been evaluating a number of wind turbines. The cooperative agreement has worked very well since the expertise of the two groups is complementary.

The wind systems can be divided into the following general categories: wind assist-electric, wind assist-mechanical, stand alone-electric, and stand alone-mechanical. In the wind assist system the wind turbine supplements power from another source, so power is available on demand whether the wind is blowing or not. If the other power source is electric, there is the added advantage that excess electricity can be fed back to the utility company. The mechanical connection through an overrunning clutch can be to an electric motor or an internal combustion engine.

Since 1981 four units have been added to the previous units: PM and Hummingbird at Wind Test Center; Enertech 44/25 and Windworker 10 at USDA. Other units located at Bushland are the DOE 17 m, DAF 40, DAF 4, and Carter 25. The UTRC is located at a Phillips Petroleum lease near Borger, TX and two Carter units are located at the Canyon Well Field.

PM

PM is a prototype which AEI is testing for the manufacturer. The unit was first installed August 1982 and then was moved to the new location in April 1983. The unit has had a number of modifications, as expected with a prototype.



HUMMINGBIRD

The first Hummingbird had a servo-motor for yaw control. From installation in March 1983 through June the unit generated 1400 kwh. The unit was damaged in high winds and was replaced by a second unit in August, which generated around 50 kwh. At the same time a foundation and electrical connections were installed for a new prototype with a gravity controlled tail for yaw control.

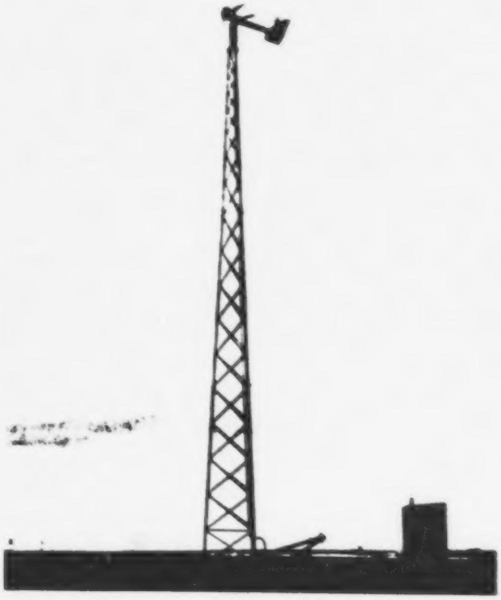


Figure 3. Hummingbird, horizontal axis wind turbine, upwind
Rating — 4 kw at 10 m/s
Generator — permanent magnet alternator, 240 V, 3 ϕ
Diameter — 4.3 m
Tower — 18.6 m height, Rohn modified for tilt down
Blades — fiberglass, fixed pitch
Overspeed control — offset yaw axis, resistance brake
Inverter — Acheval

◄ **Figure 2.** PM, horizontal axis wind turbine, down wind.
Rating — 25 kw at 10 m/s
Generator — induction, 240 V, 3 ϕ
Diameter — 10 m
Tower — 18.3 m height, steel tube, guyed with gin pole
Blades — fiberglass
Overspeed control — flexbeam and brake

ENERTECH 44/25 (USDA PROJECT)

The unit was installed June 1982 and in first year of operation produced 60,000 kwh with an availability of 95%. It was first operated at 2 degrees from designed pitch since the original brake was not strong enough. After the brake was replaced, pitch was changed to 1 degree from designed position and the unit reached a power output of 29 kw. A one degree pitch changed maximum power output by 30%. A tip brake modification in July dropped peak performance by 3 kw, but the improvement in the low windspeed range would increase the annual energy production by 5%.

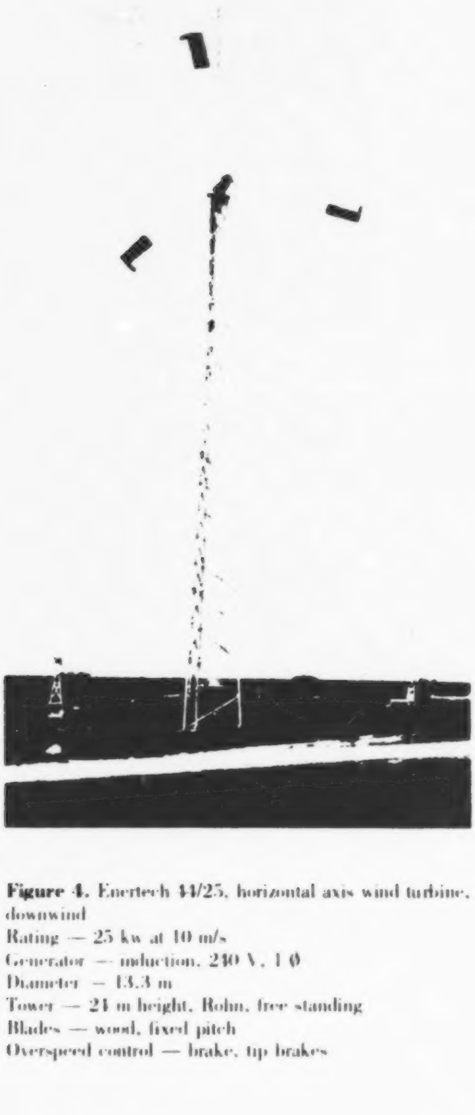


Figure 4. Enertech 44/25, horizontal axis wind turbine, downwind
Rating — 25 kw at 10 m/s
Generator — induction, 240 V, 1 Ø
Diameter — 13.3 m
Tower — 24 m height, Rohn, free standing
Blades — wood, fixed pitch
Overspeed control — brake, tip brakes

WINDWORKER 10 (USDA PROJECT)

The Windworker 10 has a permanent magnet alternator with magnets located on a large ring. This eliminates the gear box. The generator was tested in the laboratory by connecting it directly to 5 kw and 7.5 kw induction motors. Now the unit is erected in the field to test the stand alone-electrical connection to resistance heaters and electric motors. The unit can also be evaluated in the wind assist mode by using an inverter to connect it to the utility line.

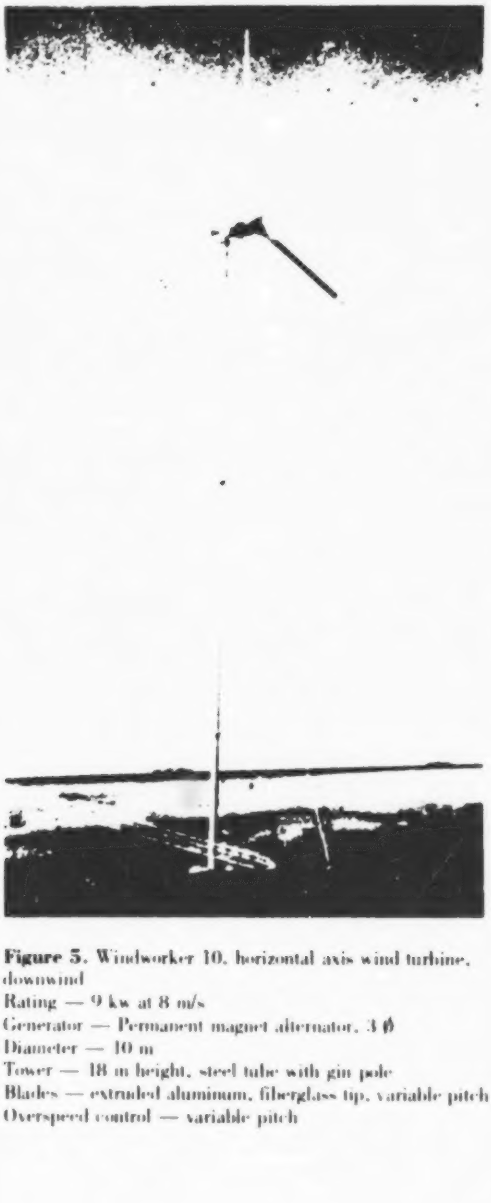


Figure 5. Windworker 10, horizontal axis wind turbine, downwind
Rating — 9 kw at 8 m/s
Generator — Permanent magnet alternator, 3 Ø
Diameter — 10 m
Tower — 18 m height, steel tube with gin pole
Blades — extruded aluminum, fiberglass tip, variable pitch
Overspeed control — variable pitch

■OTHER WIND TURBINES

CARTER 25

The Carter 25 at Bushland was moved to a new location in May 1982. This unit and the 17 meter unit suplement power to an irrigation well and sprinkler. Since installation in August 1979, the unit has produced 100,000 kwh with an availability of 76%. Because this is the first unit sold by Carter Wind Systems, modifications were expected. However in the last year of operation the availability improved to 90%.

Two Carter 25s were installed at the Canyon Well Field in March 1981. The wind turbines operate in parallel with electric motors (37 kw) for pumping water wells for the city. Excess power is fed back to Southwestern Public Service. Through June 1983 the North unit produced 71,000 kwh of which 28,000 kwh was fed back, and the South unit produced 61,000 of which 49,000 was fed back. Availability was around 75% over the period since problems occurred with the control systems, rotor, and a yaw shaft shearing. Again this was expected as these were early production units, no. 10 and no. 11. AEI has not monitored these units since the end of June.

UTRC

After installation this unit had a large amount of downtime due to modifications (brakes and control system) and minor problems such as lightning damage to control system. Therefore in the two year period it produced 18,000 kwh in 2,920 hours of operating time. With 90% availability, predicted energy output in this region would be 25,000 kwh/yr. After installation of an automatic reset on the overspeed control, the unit has been running well.

DAF 4

The small Darrieus unit is still being used as part of a test bed: stand alone-mechanical connection for pumping water from low lifts. Different type pumps will be evaluated.

DAKOTA

This DC unit was not operated during the period since the company went out of business and the size (4kw) is too small for agricultural applications.

WINGEN

Wingen 2 was moved from the location on Mr. Kirkpatrick's farm to facilitate monitoring. The rotor and nacalle had already been dismounted due to a rotor failure. The manufacturer was redesigning the rotor, overspeed control, and inserting a new microprocessor control system. AEI installed a foundation for prototype no. 3 at the first location of the Wind Test Center and then another foundation and electrical connections at the present location. In late summer the manufacturer went out of business, so this unit will not be erected.

17 METER (SANDIA AND USDA PROJECT)

Sandia Laboratories is still in charge of the low cost—17 m Darrieus wind turbine at Bushland, while USDA operates the unit. Rated power is 100 kw at 13 m/s and unit has reached a maximum output of 145 kw. The unit produced 136,000 kwh during 4,860 hours of operation. Availability was only 60% because of downtime associated with three major design changes.

DAF 40 (USDA PROJECT)

This Darrieus wind turbine is still being evaluated in the wind assist mode for pumping irrigation water. The unit is connected mechanically through an overrunning clutch to a diesel engine. At the rated windspeed, the wind turbine can save 8 liters/hr of diesel fuel.

All units evaluated by AEI and USDA have had problems, although a third generation unit, an Enertech 44/25, had a 95% availability the first year. Problems were expected since the units were prototypes or first production units. The main points to come out of this evaluation program are: (1) Reliability and maintenance are important and this can only be evaluated by obtaining operating hours on the units. (2) Small changes in pitch or other changes in the rotor can make large changes in power and annual energy production.

Data for power curves are collected with data acquisition systems, which have selectable sampling rates of 1 to 10 hz and selectable averaging times (minimum of 1 second). These data from AEI and USDA are then transferred to the DEC 10 at WTSU where they are analyzed.

■ PERSONNEL

The projects and programs conducted by AEI and USDA reflect the considerable educational and occupational experience of the staff.

Robert E. Barieau: Research Professor, Ph.D. in Chemistry, University of California at Berkeley, 1940. Dr. Barieau is in charge of data analysis, programing, and computers. Dr. Barieau also has extensive experience in thermodynamics.

Earl Gilmore: Research Professor, Ph.D. in Chemistry, University of California at Berkeley, 1951. Dr. Gilmore is also coordinator of the Amarillo College energy conservation program. During summers and part time during the year he works for AEI as project director on the UTRC wind turbine. Dr. Gilmore has experience in energy economics and power transfer.

Vaughn Nelson: Director of AEI and Professor of Physics, Ph.D. in Physics, Universiy of Kansas, 1967. Dr. Nelson teaches in Physics, writes many of the proposals and reports for AEI, and is active in the wind and solar community at the national and international level.

Pamela Mayes: Media Associate, M.A. in Art, West Texas State Universiy, 1983. Mrs. Mayes is in charge of public information, AEI Newsletter, and developing media materials, slides, graphs, brochures, video tapes, etc.

Bill Pinkerton: Research Associate, B.S. in Industrial Technology, West Texas State University, 1981. Mr. Pinkerton is responsible for maintenance and data collection for the three Carter 25 wind turbines. In addition he helps with the installation of units at the Wind Test Center.

Mark Roberson: Technical Assistant, B.S. in Plant Science, West Texas State University, 1980 and B.S. in Entomology, Texas Tech University, 1981. Mr. Roberson is responsible for data collection and maintenance of wind turbines.

Kenneth Starcher: Research Associate, B.S. in Physics, West Texas State University, 1980. Mr. Starcher has been with the program seven years and now he is in charge of the Wind Test Center, which covers installation and maintenance of wind turbines to data acquisition and analysis.

Students: Approximately 12 undergraduate students have provided technical and secretarial help. Students assist in installation, maintenance, collection and analysis of data.

Personnel from USDA: Personnel from USDA help in all phases of the program of AEI.
Dr. Nolan Clark, Project Leader, is in charge of the national wind program of USDA, which includes the program at Bushland.
Dr. Fred Vosper is in charge of the Enertech 44/25 and Windworker 10 wind turbines. He also started to analyze data from microcomputer data acquisition systems on an Apple computer.
Ron Davis is in charge of all the instrumentation, which is quite extensive with the different data acquisition systems and the transducers for each wind turbine.

■ FUNDING AND SUPPORT

Major funding was received from the State through line item funding and from USDA funds from DOE. Other funding sources were Texas Energy and Natural Resources Advisory Council (Energy Development Funds), local contributions of cash and services (such as from Phillips Petroleum Company), and West Texas State Universiy (Killgore Research Center and Department of Mathematics and Physics). The sale of electricity to Southwestern Public Service and payments from manufacturers for evaluation of their wind turbines will become more important in the future.

PROJECT FUNDING	
Line Item Funding State	$203,597
Cooperative Agreement USDA	162,000
Stripper Well Project TENRAC	10,000
WIND TEST CENTER	
Testing	4,813
WTSU (installation of utility lines)	6,010
PATRICK ACKER MEMORIAL FUND	2,850
SUPPORT FROM WTSU	
Instrumentation Killgore Research Center	17,622
Computer Time Killgore Research Center	9,468
Computer Time Math and Physics Dept.	5,500
OTHER	
Electricity Sold to SPS	1,426
Information Services	837
In Kind Services Phillips Petroleum Company	16,582
CONTRIBUTIONS	
Dr. Robert Barieau	5,255
Matching Funds from Chevron 2 for 1	10,000
Barbara McBride	250
Matching Funds from Exxon 3 for 1	750
Dr. Earl Gilmore	400
Dr. Vaughn Nelson	500
Shirley Harrell Howse	100
TOTAL	$457,960

■ PATRICK ACKER MEMORIAL

In March 1982 Patrick Acker was electrocuted in an accident during work on the foundation for a wind turbine. Previous scholarship funds of AEI were combined with donations from AEI, USDA, Sandia Labs, and others to form a memorial scholarship. Interest from the fund will be used to give annual scholarships in physics and/or alternative energy. Patrick's accumulated contribution of five years in our program is sorely missed.

■ PUBLICATIONS AND REPORTS

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2. Earl Gilmore, "Energy Transfer in Wind Assist Electric Power Systems," *Wind Engineering*, Vol 5, No 3,1981, p 162.

3. Vaughn Nelson, R. Nolan Clark, and Robert E. Barieau, "Wind Power in the United States—Irrigation Pumping," *Wind Engineering*, Vol 6, No 2, 1982, p 95.

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7. Vaughn Nelson and Enrique Caldera, "Wind Energy in Latin America," Conferencia Mundial del Sistemas, Caracas, Venezuela, July 11-15, 1983.

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15. Vaughn Nelson, "Windwatch," *Spectra*, Vol VI, No 1 1982.

16. Vaughn Nelson, "Institutional Aspects of Wind," *Spectra*, Vol VI, No 2, 1982.

BROCHURES AND PAMPLETS

Brief Discussion of Wind Energy in Texas

Wind Energy Conversion Systems: Texas Manufacturers and Dealers

List of SWECS Manufacturers

Information on Building Your Own System

Economics of Wind Turbines

USDA has a number of articles and reports on wind energy projects. Write to Wind Energy Laboratory, USDA, Drawer 10, Bushland, TX 79012.

REPRINTS AVAILABLE

U.S. DEPARTMENT OF AGRICULTURE
WIND POWERED IRRIGATION RESEARCH, DRAWER 10, BUSHLAND, TX 79012

JULY, 1985

MANUSCRIPTS

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Clark R.N. and F.C. Vosper, "Long Term Performance of Wind-Driven Induction Generators", ASAE Paper No. 84-4548, 1984.

Clark, R.N., "Co-Generation Using Wind and Diesel for Irrigation Pumping", ASAE Paper No. 84-2603, 1984.

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WIND ENERGY ACTIVITIES AT THE INSTITUTO DE INVESTIGACIONES ELECTRICAS (ELECTRIC RESEARCH INSTITUTE) OF MEXICO

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Instituto de Investigaciones Eléctricas
Apartado Postal 475
Cuernavaca, Mor; 62000
México

ABSTRACT

This paper is a summary of the wind energy activities carried out by the Electric Research Institute of México, since 1977, and of the present and future projects.

Since 1977 the Instituto de Investigaciones Eléctricas (IIE), of México, begans a project called "Wind Energy Use". This project was conceived in order to carry out studies on three basic aspects:

a).-Meteorology
b).-Systems and Applications Analysis
c).-Wind Energy Conversion Systems Development. For this,three sections with the followings goals and specific objectives were established.

Meteorologyc section
Goals:

1.- Wind energy resource evaluation in México
2.- Best sites for wind energy use localization

Specific Objectives:

1.-Methodologies development for prospecting, measuring and processing data, in order to evaluate the wind energy resource at specific sites.
2.-Gradual program development for sites selection, with the assistance of Superior Educational Centers.

Underframe:

Anemometric equipment, wind energy climatologyc mobile laboratory and VAX-VMS computer system.

Fulfilments:

1.- "Preliminar Wind Atlas of México", published by the Latin-American Energy Association in 1984.
2.- "Wind Energy Meteorology Manual", published by the Latin-American Energy Association in 1984
3.- "Guide for the Design, Habilitation and Operation of Mobile Laboratories for Wind Energy Climatology", published by the Latin-American Energy Association in 1984.
4.- Six sites Wind Energy Evaluation.

Instrumentation Section.
Goals:

1.- Data acquisition systems development.
2.- Control and performance testing equipment development for wind energy conversion systems.

Specific Objectives:

1.- Digital printed output data electronic anemometer
2.- Microprocessor based wind data acquisition system with solid state memory output data device.
3.- Automatic Weather data acquisition system
4.- Moderate capacity wind energy conversion systems controls

Underframe:

Electronic Laboratory, Computer for microprocessor based systems development.

Fulfilments:

1.- Wind energy climatology mobile laboratory
2.- Wind energy conversion systems performance testing, data acquisition system.
3.- Digital printed output data electronic anemometer
4.- Microprocessor based wind data acquisition system with solid state memory output data device.
5.- 10 KW wind energy conversion system control

Systems and Applications Analysis Section
Goals:

Market, systems and applications studies related to water pumping and electric power generation.

Specific Objectives:

1.- Electric power generation.

  - 1.1.Stand alone systems
  - 1.2.Utility conecting systems
  - 1.3.Wind Farms

2.- Water Pumping
  - 2.1.Domestic use
  - 2.2.Irrigation

Fulfilments:

1.- "Wind Energy Conversion Systems for Water Pumping Monograph" prepared for the Agriculture and Hydraulic Resources Secretariat.
2.- "Economic Analysis for Water Pumping Wind Machines", published by the Latin-American Energy Association, 1983.
3.- Several papers about Wind-Driven water pumping systems presented at National and International meetings.
4.- "Manual for Interconecting Moderated Capacity Wind Turbines to Distribution Networks", published by the Latin-American Energy Association, 1985.
5.- "Standar Practices for Interconecting Wind Turbines to Distribution Networks".
6.- "Technical Proposal for Wind Co-generation at the Ventosa, Oaxaca".

Wind Energy Conversion Systems Development Section
Goals:

Wind energy conversion systems development, for applications in México, according to wind climatology of the country. In order to transfer the technology to the Electrical and Metal-Mechanical National Industry.

Specific Objectives:

Water Pumping:

1.- Low cost, high efficiency and high reliability system for domestic and watering place for cattle use
2.- Wind turbine generator - electrical pump system in the range of 10 to 50 KW for irrigation and potable water.

Electric Power Generation.

1.- Micro-electric generation.- Low cost, high efficiency and high reliability 1.5 KW system, for domestic and telecomunications stations use.
2.- Cogeneration.- 50 KW wind turbine generator for use in wind farms interconected to the utility distribution networks or for hybrid use with a disel generator.

Underframe:

1.- Wind Energy Experimental Station/Test site, "El Gavillero" with:

   a). Three towers for wind machines mounting
   b). Meteorologyc Instrumentation
   c). Control room
   d). WECS performance testing equipments.
   e). Lodging
   f). Storage house
   g). Stationary technical personal

2.- Wind Tunel.- with two testing sections for 1.10 and 0.78 mts., maximun speeds of 20 and 45 m/s and 1×10^6 and 2×10^6 Reynolds number.
Open type, with a 30 Hp controled speed D.C. motor.
Hot wire anemometric system, Pitot tubes and microcomputer for data acquisition.

3.- Mobile Workshop
Two arranged vehicles for installing and testing WECS.

4.- Fulfilments

The fulfilments of the wind Energy Conversion Systems Development Section are presented in the next page as a table.

Description	Name	Axis		Type		No. Blades	DIAMETER (m)	HEIGHT (m)	BLADES TYPE	POWER	Coments
		H	V	U	D						
Wind Driven-Water pumping System	Savonius		✓			4*	0.92	3.60	steel	-	$0.7m^3$/H for 10 mts water depht at 4m/s
Wind Driven-Water pumping System	Sails type	✓		✓		3	7.6	-	Nylon Sails	6.7 Hp at 32 km/h	
Wind Driven-Water pumping System	ITIA	✓		✓		5	2.5	-	Steel	200 watts at	Low cost
Wind Driven-Electrical water pumping system	Albatros 2	✓			✓	3	11	-	fibber glass	-	Prototype under test
Wind turbine Generator	200 W		✓			3*	0.56	3	steel	150 watts at 11 m/s	
Wind turbine Generator	1.5 KW	✓			✓	3	4.8	-	Aluminum	1.5 KW at 10 m/s	
Wind turbine Generator	Fenix	✓		✓		3		-	steel	1.5 KW at 12 m/s	
Wind turbine Generator	Albatros 1	✓			✓	3	11	-	Dacron Sails	8Kw at 10 m/s	Utility tied with synchronous inverter

(1) H=Horizontal
V=Vertical
(2) U=Up Wind
D=Dow Wind

* Buckets

PRESENT PROGRAMMED PROJECTS

Meteorology Section:

Title: "Wind Energy Resource Evaluation at the Ventosa, Oaxaca" (2TH Phase)

Objective: To complet the wind energy resource evaluation begun at 1rst phase.

Goal: Use of the resulting information in a simulation computer program, for interconecting wind farms to the utility distribution networks at the Ventosa, Oaxaca.

Instrumentation Section:

Title: "Design, Construction and test of an Automatic Weather Station".

Objetive: Transfer the technology to the National Electronic Industry for its principal application in the National Weather Service.

Goal: To increase the automatization and reliability of the acquired data.

Systems and Application Analysis Section:

Title: "Computer program for simulating Co-generation of Wind Farms tied to the utility distribution networks".

Objetive: To have a simulation model for determining the best sites for assessment of wind farms, and for predicting its effects on the utility distribution networks.

Goal: Simulation and Design of a 1 MW wind farm.

Wind Energy Conversion Systems Development Section:

Title: "Design, Construction and test of a 50 KW wind turbine generator".

Objetive: Transfer the technology to the National Industry for its principal application as an utility tied system.

Goal: To prove the technical economic feasibility of the WECS develpment in México.

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